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OEM Summary Report on the Effects of Disinfectants on Aircraft Flight Deck Materials

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16. Abstract

Due to the COVID-19 worldwide pandemic, aircraft owners and operators may find it necessary to more frequently and thoroughly disinfect airplanes. The increased use of disinfectants on aircraft materials leads to the possibility of material degradation or negative impacts on equipment performance.

This report summarizes disinfection testing performed by various original equipment manufacturers (OEMs) for flight deck materials and components. These OEMs performed tests on materials with thermal disinfection, Ultraviolet (UV) disinfection, and various liquid disinfection methods. After disinfectant exposure, they evaluated the materials for visual and mechanical deterioration. Also summarized in this report is a survey of aircraft operators on the disinfecting methods that are used in practice in cockpits.

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Acronyms

Acronym	Definition
ACP	Audio Control Panel
A/P	Auto Pilot
BRDF	Bidirectional Reflectance Distribution Function
C	Celsius
CCD	Cursor Control Device
CDC	Center for Disease Control and Prevention
cfm	Cubic Feet per Minute
CPVC	Chlorinated Polyvinyl Chloride
DOT	Department of Transportation
DCP	Display Control Panel
EFIS	Electronic Flight Instrument System
FAA	Federal Aviation Administration
FST	Fire Smoke and Toxicity
IPA	Isopropyl Alcohol
J	Joule(s)
J/cm^2	Joules per Centimeter Squared
LRU	Line Replaceable Unit
M	Meter(s)
MJ/m^2	Mega Joule(s) per Meter Squared
mJ/cm^2	Millijoule(s) per Centimeter Squared
Mic	Microphone
MKP	Multifunctional Keypad
NIAR	National Institute for Aviation Research
nm	Nanometer(s)
NSD	Negligible to Slight Discoloration
OEM	Original Equipment Manufacturer
RH	Relative Humidity
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
TCP	Tuning and Control Panel
UV	Ultraviolet
W	Watt(s)
WXR	Weather Radar

Executive summary

As a result of the COVID-19 public health crisis, there is an increased need for frequent and thorough disinfection of aircraft interiors. The impact of exposure to disinfectants on flight deck materials was investigated by multiple original equipment manufacturers (OEMs).

The OEMs performed testing on a variety of materials, including electrical components from flight decks such as instrument panels and displays. Disinfection methods tested include Ultraviolet (UV) radiation, thermal treatments, and liquid disinfection. Each OEM used different products and procedures. At least two OEMs examined the impact on materials of UV radiation, thermal exposure, Isopropyl Alcohol (IPA), Sani-Cide EX3, and Calla 1452 in different capacities.

Each OEM determined the effect of repetitive disinfection on materials using different evaluation standards. OEM 1 evaluated material appearance based on color standards and gloss measurements, and checked the functionality of flight deck instruments in between applications of disinfectant. OEMs 2, 3, 4, and 6 only measured changes in material appearance. In OEM 2's testing, materials underwent optical and visual tests. OEMs 3 and 6 based results on a visual inspection, while OEM 4 took quantitative luminance and chromaticity measurements. OEM 5 also evaluated material appearance with a visual inspection, but additionally measured mechanical properties of their materials such as fire/smoke resistivity, corrosion, and tensile strength.

In addition to the OEM testing, the FAA took a survey of multiple aircraft operators to determine which disinfectant methods are used in practice in aircraft cockpits and cabins. Operators provided information about what disinfecting methods were used, including specific product names, who performs the disinfection, and how frequently the processes are performed. This operator disinfecting survey is in Appendix G of this report.

1 Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the virus that causes the disease COVID-19 in humans. This disease can cause serious symptoms such as respiratory illness, high fever, shortness of breath, and extreme body aches. Respiratory failure may occur if the body's immune system fails to beat back the virus, and this failure may lead to death. SARS-CoV-2 is spread from person-to-person by breathing, talking, sneezing or coughing. These methods all drive particles through the air whereby a nearby person could potentially inhale them. Moreover, these particles can be deposited on skin or on surfaces in the surrounding area.

Limiting the spread of such viruses has become a major concern in the aviation industry and resulted in the increased need for frequent and thorough disinfection of aircraft interiors. Although most disinfectants have been proven to work on surfaces to prevent the virus from spreading, the negative impact these disinfectants will have on flight deck materials after long-term use is unclear. Therefore, studies were conducted by various Original Equipment Manufacturer (OEMs) to determine which cleaning methods will effectively disinfect while causing the least amount of degradation when being used in the aircraft flight deck. This report does not directly include antiviral efficacy of the disinfection methods.

1.1 Overview

To determine the best approach for disinfecting a flight deck while causing minimal degradation to materials, five OEMs conducted material testing with various disinfection methods and procedures. Table 1 lists the disinfection test methods of each OEM and Table 2 lists the materials they tested. The purpose of this report is to provide a summary of the testing done by each OEM. Original OEM report documents are included in the appendix. These documents include some tests done on cabin materials, but only testing done on flight deck materials and components is discussed in the summaries.

Table 1. Disinfection test methods

OEM 1	Far-UV, Thermal, Liquid (IPA, Sani-Cide EX3, Calla 1452, Peroxigard)
OEM 2	Liquid (IPA, Sani-Cide EX3, Ozone, Vital Oxide, Diversey OxiVirTB, Ecolab Aperoxide Multisurface, M-Zone Wipes)
OEM 3	UV-C, Liquid (Hydrogen Peroxide)
OEM 4	UV-C
OEM 5	UV-C, Thermal, Liquid (Calla 1452, Netbiokem)
OEM 6	UV-C

Table 2. Materials tested

OEM 1	Far-UV: unspecified electrical components from flight decks
	Thermal: painted aluminum/acrylic back plate, anti-reflective glass indicator lens, poly II acrylic pushbutton
	70% IPA, Sanicide EX3: display unit, cursor control device, EFIS control panel, parking brake assembly, multifunction keypad, flap module assembly, display unit, display control panel, clock / mic, audio control panel, gage number clicker, a/p switch, wxr panel
	Calla 1452 (wipe): cursor control device, parking brake assembly, flap module assembly, display control panel, clock / mic, gage number clicker, a/p switch
	Calla 1452 (e-spray): audio control panel, P5-13 electric meters, battery and galley power panel, P5-6 cabin pressure selector panel, PR-2 fuel control panel, cabin altimeter - differential pressure indicator, mode control panel, alerting and transponder control, multifunction keypad, audio control panel, tuning and control panel, display control panel
	Peroxigard (spray bottle): parking brake assembly, knobs
	Peroxigard/Calla 1452 (e-spray): first officers side, overhead panels, aisle stand
OEM 2	undisclosed
OEM 3	UV-C: pushbuttons, plastic guards, knobs, leather
	Hydrogen Peroxide: cockpit dado panel paint
OEM 4	UV-C: cockpit instrument panels
OEM 5	UV-C: PU-coatings, polytherimide, polycarbonate, textiles (wood/polyamide mix), textiles (seat belt fabric polyester), artificial leather, leather, carpet
	Calla 1452, Peroxigard: cockpit panels
	Hydrogen Peroxide: tray table material
OEM 6	UV-C: avionics display panel, AerForm

2 Report summaries from OEMs

2.1 Original equipment manufacturer 1

OEM 1 conducted tests on flight deck materials and components with 70% Isopropyl Alcohol (IPA), Sani-Cide EX3, Calla 1452, and Peroxigard. Each material was checked against color standards and gloss measurements to determine whether there was any significant change in appearance. Functional checks were also conducted after testing disinfectants with an electrostatic sprayer or spray bottle. OEM 1 defined significant degradation in their results as moderate to severe discoloring, yellowing, fading or clouding, as well as abnormalities or alterations in appearance, performance, reflection loss, or texture.

Testing with 70% IPA and Sani-Cide EX3 was conducted on the same 14-line replaceable units (LRUs) shown in Table 3. The 70% IPA was applied to half of the LRU surface with a saturated cloth. After a 10-12 minute dwell time, the surface was wiped dry and left for two hours. This process was repeated for a total of 20 applications; after each application pictures were taken to evaluate damage. Sani-Cide EX3 was applied to the other half of the LRUs with a spray bottle. After a 10-12 minute dwell time, each surface was wiped dry with a cloth and left for 10-15 minutes. Pictures were taken after every 10 applications.

The results of the 70% IPA testing were based off color scheme comparisons and gloss measurements. It was determined that the disinfectant had negligible effects on the appearance of LRUs. Testing with Sani-Cide EX3 was suspended after 16 applications due to function check failures and primer adhesion failure seen on the flap module assembly. The disinfectant left behind a sticky residue even after the surface was wiped dry, as well as streaks of dried liquid shown in Figure 1. It was concluded that these poor results were likely due to the pools of liquid left by the spray bottle application method.

An additional eight LRUs, found in Table 4, were tested with Calla 1452 using the same wiping procedure as the testing with 70% IPA. The results of the disinfection with Calla 1452 showed that changes in gloss were minimal throughout the 20 cycles of testing, and comparison with color standards showed no change in appearance.

Table 3. LRUs tested with 70% IPA and Sani-Cide EX3

	Description
1	Display Unit
2	Cursor Control Device (CCD)
3	Electronic Flight Instrument System (EFIS) Control Panel
4	Cursor Control Device (CCD)
5	Parking Brake Assembly*
6	Multifunction Keypad (MKP)
7	Flap Module Assembly
8	Display Unit
9	Display Control Panel (DCP)
10	Clock / Mic

	Description
11	Audio Control Panel (ACP)
12	Gage Number Clicker
13	A/P Switch
14	WXR Panel

Table 4. LRUs tested with Calla 1452 wiping

	Description
1	Cursor Control Device (CCD)
2	Cursor Control Device (CCD)
3	Parking Brake Assembly
4	Flap Module Assembly
5	Display Control Panel (DCP)
6	Clock / Mic
7	Gage Number Clicker
8	A/P Switch

Figure 1. Sticky residue and streaks of dried Sani-Cide EX3

Peroxigard was tested on a parking brake assembly and seven knobs of various color schemes. All tested items were evaluated for damage by comparison with color standards, and gloss measurements were taken for only the parking brake assembly. Peroxigard was applied to surfaces using a spray bottle from 6-8 inches away. After one minute the surface was dried with a cloth, then left for 10 minutes to dry. A total of 50 applications were completed, pictures and gloss measurements were taken after every 5 applications. It was determined that Peroxigard does not adversely affect the appearance of the parking brake assembly or knobs, although after 14 applications some paint smearing occurred in the recessed labeling of two knobs (Figure 2).

Figure 2. Smearing of paint on knobs

Peroxigard and Calla 1452 were later tested again in a representative flight deck using an electrostatic sprayer. Areas tested were the first officer’s side, the overhead panels, and aisle stand. During application, liquid pooling and dripping were avoided when possible, and liquid indicator tape was applied to the LRUs to indicate liquid ingress. Both Peroxigard and Calla 1452 were applied 20 times, function checks on the LRUs were performed after each day of testing. Liquid ingress was first indicated after four applications of Calla 1452. After ten applications, the function checks showed a number of issues, including stuck buttons, dimmed assembly lights, and a transponder that would not go into standby. The final function check for the Calla 1452 testing showed that the assembly lights were still dimmed and the transponder still would not go into standby. In the Peroxigard testing, no liquid ingress was indicated throughout the 20 applications. However, the final function check showed that three lights were non-functional, switches were sticky from residue, and residue was left on the plastic windows (this material was not representative of aircraft windows).

A third phase of Calla 1452 testing was conducted on the LRUs listed in Table 5. The first and second phases of testing with Calla 1452 were previously discussed, the first phase applied Calla 1452 with a cloth, while in the second phase it was applied with an electrostatic sprayer.

Table 5. LRUs tested with Calla 1452 electrostatic spray

	Description
1	Audio Control Panel (ACP)
2	P5-13 Electric Meters, Battery and Galley Power Panel
3	P5-6 Cabin Pressure Selector Panel
4	PR-2 Fuel Control Panel
5	Cabin Altimeter – Differential Pressure Indicator
6	Mode Control Panel
7	Alerting and Transponder Control
8	Multifunction Keypad (MKP)
9	Audio Control Panel (ACP)
10	Tuning and Control Panel (TCP)
11	Display Control Panel (DCP)

In the third phase, six rounds of testing were completed. Each round was intended to result in more wetting than the previous test round. These tests also used an electrostatic sprayer; however, a robotic arm was used to apply the disinfectant to minimize variability of application. Liquid indicator tape was used to show liquid intrusion and function checks were conducted in each round. Each round had procedure adjustments such as changes to spray velocity and number of applications. After all six rounds of testing, a total of 210 applications had been done. At 90 cumulative applications, all LRUs exhibited signs of liquid ingress, and a corrosion product was first observed. Function checks at this point indicated that most LRUs were not significantly affected by the liquid intrusion. After 130 applications, the first functional issue was observed; however, the correlation of the issue to Calla 1452 could not be confirmed. After 210 applications, several LRUs were no longer fully functional and many showed indications of concentrated fluid residue between surfaces. Evidence of corrosion was clear at fasteners, knobs, and some electric boards.

In addition to testing liquid disinfectants, OEM 1 also conducted a series of thermal disinfection tests with four 1.6 kW heaters and two >600 cfm actively controlled fans. The purpose of these heating tests was to determine the length and intensity of heat exposure required for disinfection against SARS-CoV-2. Testing performed with the airplane unpowered proved the most successful. During this test, the heater assemblies were positioned in the captain's and first officer's seats, with the exit air aimed directly at target disinfection surfaces (Figure 3). Thermocouples and a thermal imaging camera monitored surface temperatures during testing (Figure 4). Although the effect of the elevated temperatures on materials was not monitored during the tests, it can be assumed that there was no effect since testing was done below the threshold the materials are rated for.

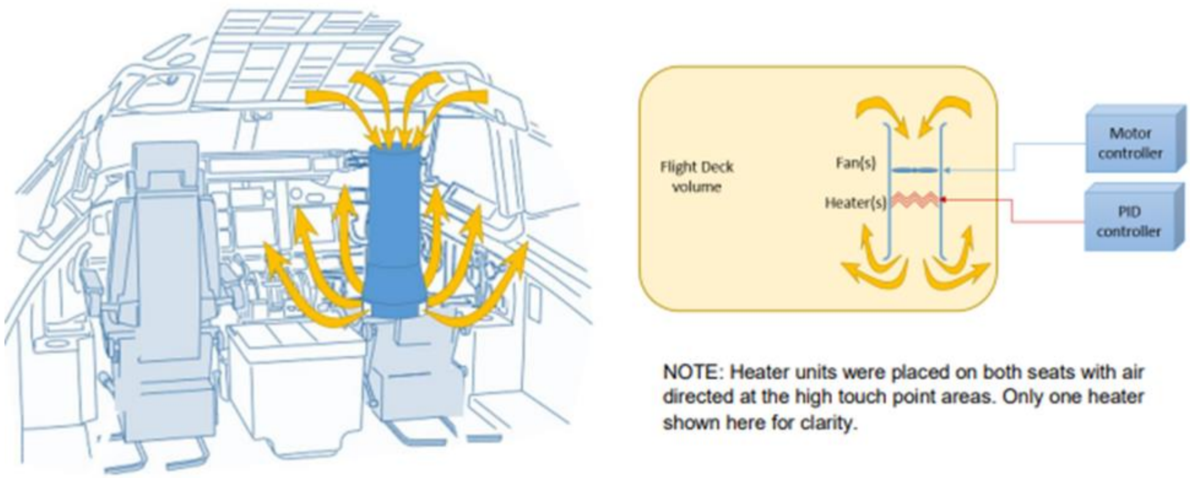


Figure 3. Thermal disinfection setup

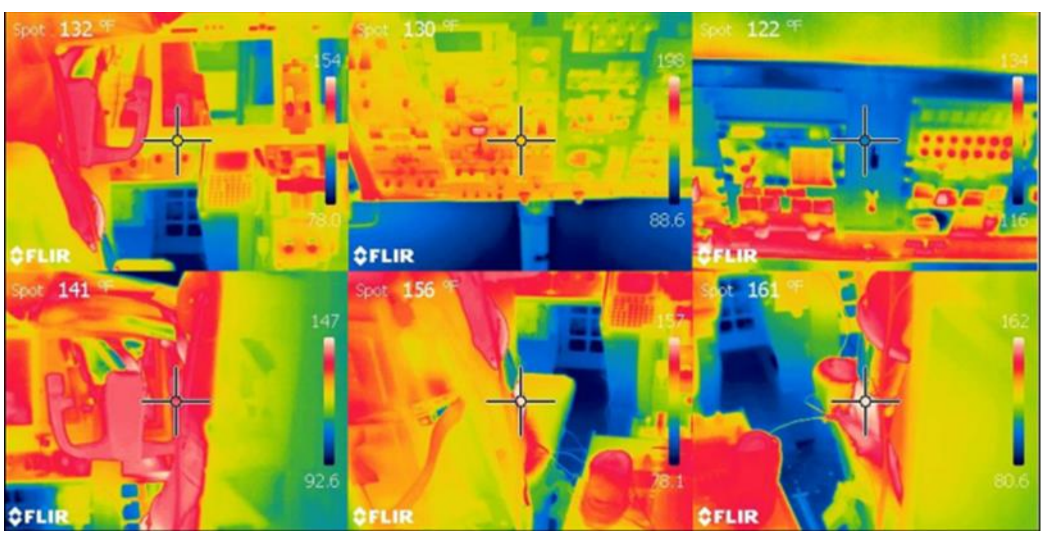


Figure 4. Thermal camera flight deck images

Lastly, OEM 1 tested Far-UV exposure disinfection in the flight deck (Figure 5). Their paper discussed the efficacy of 222nm Far-UV light against Sars-CoV-2, and the applicability of its use in an aircraft environment. While the majority of OEMs used UV-C light, OEM 1 used Far-UV light. UV-C light lies in the 240 - 280 nm region of the spectrum (254 nm sources being most prevalent) and Far-UV lies in the 200 to 235 nm region (222 nm sources being the most prevalent). While both wavelengths are germicidal, Far-UV systems were more recently developed and may be safer and more effective than the UV-C systems. Testing was conducted with a mobile wand prototype that subjects target disinfection surfaces to a Far-UV 222 nm dose of 3 mJ/cm2. This dosage is effective in combating transmission of SARS-CoV-2. The wand contained a cylindrical lamp composed of krypton and a small amount of chlorine gas. An operator simply had to pass the wand over high contact surfaces to disinfect them, proving it capable of sanitizing an area such as the flight deck within 15 minutes. The study also referenced a series of exposure tests to individual electronic components in controlled environments.

Figure 5. Far-UV wand prototype

2.2 Original equipment manufacturer 2

OEM 2 tested seven cleaning products: OEM 2's cleaning kit (50% isopropyl alcohol (IPA), 50% de-ionized water), Sani-Cide EX3, Ozone, Vital Oxide, Diversey OxiVirTB, Ecolab A Peroxide Multisurface, and M-Zone Wipes – Micronova. Testing was conducted on the surface coatings of display assets and components. These surfaces were tested using microfiber cloths or a cloth closely related. The evaluation methods used were optical and visual tests. The optical test included first surface specular reflectance, bidirectional reflectance distribution function (BRDF), and transmissive haze on single substrates. The visual test consisted of a visible inspection.

Of the seven cleaning products, OEM 2's cleaning kit was the only one that showed no significant degradation in both the optical and visual tests. The kit used was only valid for the cleaning process; according to the Center for Disease Control and Prevention (CDC) a higher percentage of IPA is required to disinfect surfaces against SARS-CoV-2. Materials tested with Ozone showed visible changes after 168 hours of exposure. The optical test showed that Sani-Cide EX3, Diversey OxiVirTB, and Ecolab Aperoxide Multisurface significantly affected the material after 10 exposures. Vital Oxide and M-Zone Wipes also affected materials after 10 exposures, and significantly changed their optical test results after 100 exposures.

2.3 Original equipment manufacturer 3

OEM 3 conducted two tests in the flight deck: short-term exposure of sanitizing products and UV-C exposure.

In the short-term test, 3% hydrogen peroxide was the only disinfectant tested on a flight deck material. The method for testing was to take a soft cotton cloth saturated with the disinfectant and keep it on the test article for varying times (15 minutes, 1 hour, 6 hours, 12 hours, 24 hours, and 48 hours). The flight deck material tested was cockpit dado panel paint, which was unaffected after exposure to hydrogen peroxide. Testing on common aviation textiles with vaporized hydrogen peroxide (VHP) led to loss of mass, degradation of tensile strength, and unacceptable increases in the flame time of wool blends. This data is located in DOT/FAA/AM-09/16. (S. F. Chou, 2009).

In the UV-C exposure tests, three different energy levels were tested (3 J/cm^2, 10 J/cm^2, and 20 J/cm^2) in addition to a control group (0 J/cm^2). The materials tested were cockpit pushbuttons, plastic guards, knobs, and leather from the pilot's seat. The UV-C source, shown in Figure 6, included a plate with three 18 W UV-C lamps each emitting light at a wavelength of 254 nm. With the UV-C lamp on, portions of each material were gradually uncovered to achieve 20 J/cm^2 on the first portion, 10 J/cm^2 on the next uncovered portion, and 3 J/cm^2 on the last portion uncovered. All sections underwent a visual inspection and showed no visible degradation.

Figure 6. OEM 3 UV-C source

2.4 Original equipment manufacturer 4

OEM 4 conducted UV-C exposure tests on a cockpit touchscreen display and cockpit instrument panels. These tests were performed to validate the lifetime exposure limits of the units. The OEM conducted testing using a Rayonet reactor equipped with 16 mercury vapor UV-C lamps arranged around the circumference of a cylinder of UV-reflective material. This reactor is shown in Figure 7.

Figure 7. Reactor used for UV-C exposures

Measurements and pictures were taken pre- and post-exposure to evaluate changes in appearance. The cockpit touchscreen display was subjected to 253.7 nm UV-C exposure that varied from 0 J/cm2 to 20 J/cm2. The component was covered in sections with masking tape, leaving one section unmasked. This section was exposed to UV-C and then one additional section was unmasked. This procedure was repeated to obtain a sample with sections reflecting different exposure doses. The sections are shown in Figure 8. A visual inspection after testing showed no detectable changes to the display, bezel, or buttons. In the area of the display that was exposed to 10 J/cm2, quantitative luminance and chromaticity measurements were taken. Less than 0.01 delta color shift was observed and less than 3% luminance shift was observed. These changes were attributed to test setup and normal equipment variations.

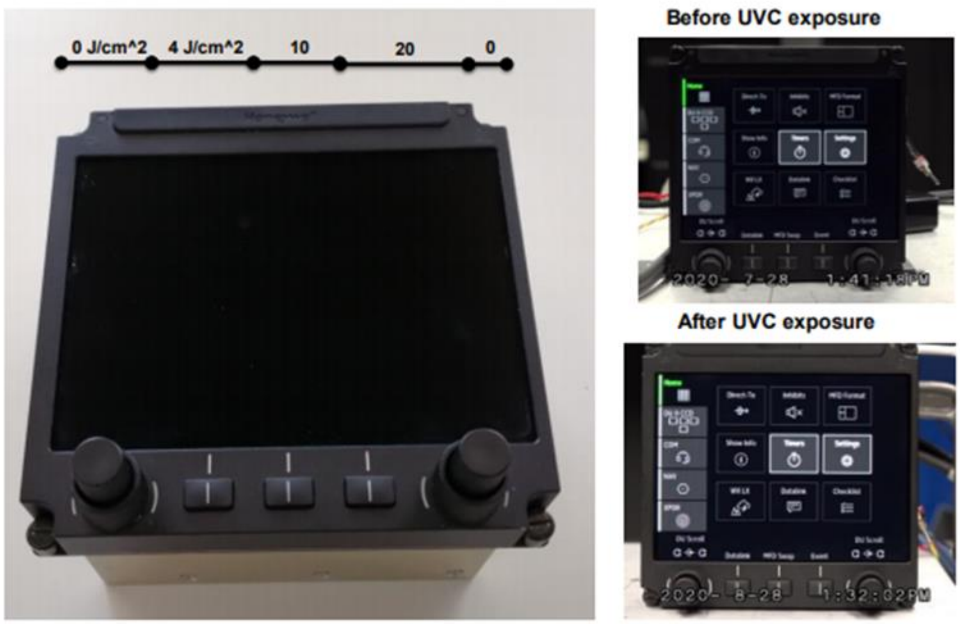


Figure 8. UV-C exposure to cockpit display

The assorted small instrument panels were also tested using progressive UV-C exposure (Figure 9). No changes in appearance were noted with the increasing exposure, and all buttons remained functional.

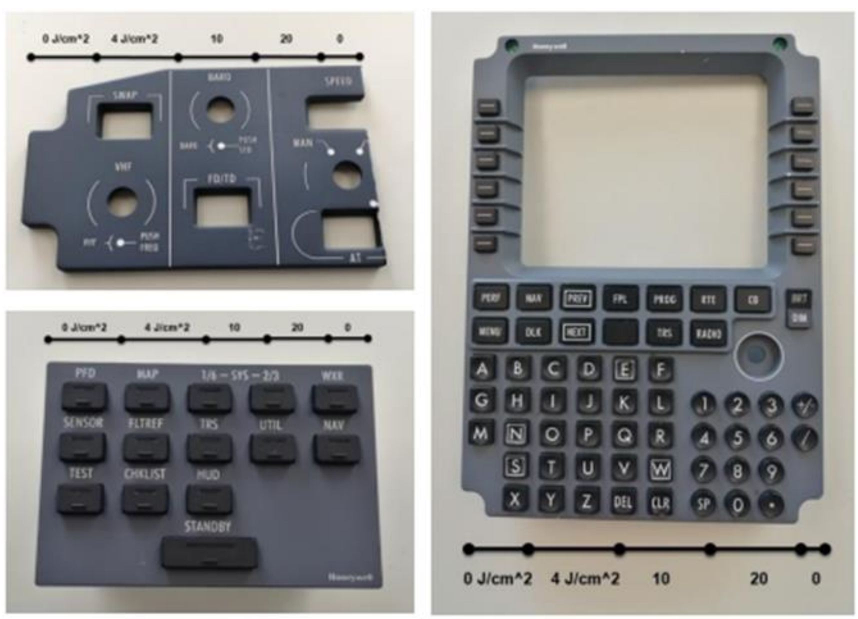


Figure 9. UV-C exposure to cockpit instrument panel

2.5 Original equipment manufacturer 5

OEM 5 tested the material compatibility of four different disinfection methods: liquid disinfection, gaseous disinfection, thermal disinfection, and UV-C exposure. Each method was evaluated to determine its effect on the materials visual appearance, fire/smoke resistivity, and tensile strength/corrosion.

Two tests were performed with liquid disinfectants. The first test applied the disinfectant Netbiokem through electrostatic fogging, while the second test used an electrostatic sprayer to apply Calla 1452. Both tests resulted in a significant change in performance for soft materials in the fire/smoke resistivity and tensile strength/corrosion areas of evaluation. These tests also caused degradation in visual appearance. Due to the nature of these disinfection methods, the OEM also expects them to cause negative long-term effects in hidden areas of the aircraft where the disinfectant is likely to accumulate, such as the A/C system and in between sensitive electrical surfaces.

Gaseous hydrogen peroxide was also tested as a disinfectant and some materials such as Nylon and textiles showed sensitivity to highly concentrated hydrogen peroxide vapor. The OEM suspected that the continuous subjection to the high concentration of hydrogen peroxide over a very long period might have led to the observed bleaching of Nylon and loss of flame resistance at some textiles and noted that repetition of the test under more realistic conditions would potentially modify this observation. Aircraft cabin pressure controllers exposed to hydrogen peroxide showed full performance after exposure and did not show signs of corrosion or deterioration.

Three thermal disinfection tests were conducted. The first test was conducted at 11% relative humidity (RH) and 55ºC, the second test was run overnight for seven hours at 17% RH and 40ºC, and the third test ran for 270 minutes at 20% RH and 46ºC. All three tests did not affect fire/smoke resistivity, visual appearance, or tensile strength of the materials. They further concluded that thermal disinfection is compatible with aircraft equipment as well as the A/C system. However, they recommend performing thermal disinfection with the aircraft unpowered and certain temperature sensitive A/C items removed.

OEM 5 used 12 36-watt UV-C lamps inside a wooden 1m x 1m x 1m box (Figure 10) with aluminum inner surfaces to test the effect on materials of UV-C disinfection.

Figure 10. UV radiation box

The following flight deck materials were tested on: PU-Coatings, Polyetherimide, Polycarbonate, textiles (wool/polyamide mix), textiles (seat belt fabric polyester), artificial leather, leather, and carpet. Materials were subjected to 1 MJ/m^2 of UV-C light with a wavelength of 254 nm. This dose simulated approximately 14 years of daily disinfection. All UV-C testing results are shown in Table 6, which is adapted from the results table in OEM 5's original report document that is contained in the appendix. Results were measured based determined based on color impact, mechanical impact, and FST (Fire Smoke and Toxicity) properties.

Table 6. OEM 5 UV-C testing results

Material Type	**Application**	**Color Impact**	**Mechanical Impact**	**FST Impact**	**Remarks**
PU-Coatings	Decorative surfaces	None	None	None	All specimens have been exposed to 1 MJ/m2 @ 254 nm
Polyetherimide	Heat release compliant thermoplastic parts, e.g. passenger service unit (PSU)	Yellowing	None	None	
Polycarbonate	Transparencies	Yellowing	None	None	

Material Type	Application	Color Impact	Mechanical Impact	FST Impact	Remarks
Textiles - Wool / Polyamide mix	Curtains, Flightdeck seats	Slight color shift	Loss of tear resistance	None	
Textiles - Seat Belt Fabric Polyester	Seat belts	None	Loss of tear resistance	None	
Artificial Leather	Seats	None	Increase of tear resistance	None	
Leather	Seats	None	N/A	significant increase in burn length	
Carpet	Cockpit floor	Yellowing depending on the material composition	N/A	N/A	

2.6 Original equipment manufacturer 6

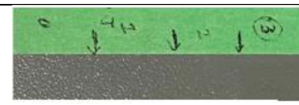
OEM 6 conducted tests to determine the impact of 254nm UV-C light on an avionics display panel and the material AerForm. The material appearance was evaluated for negligible to slight discoloration (NSD). Based on a visual inspection, the interval of exposure after which the material still looked unaffected or slightly affected was determined. Each interval of exposure subjected materials to ~50J/cm^2 of cumulative fluence.

The setup for the tests included amalgam UV-C lamp bulbs affixed to an aluminum fixture. UV-C exposure was measured in terms of irradiance and fluence. Irradiance is the measure of the amount of UV-C light hitting a unit area in a unit time, while fluence is the measure of the total amount of UV-C energy hitting a unit area. An autonomous robot RAY was programmed to move the UV-C source over the surfaces under test at a fixed speed. A single pass of RAY with all lamps operating cast 15 mJ/cm^2 on each surface.

The AerForm was exposed to a total of 146 J/cm^2, at which point NSD was observed. The avionics display panel did not show any discoloration after a total UV-C exposure of 305 J/cm^2.

It was noted that both the glass and the display panel border were exposed. Table 7 shows the results of the appearance test for the flight deck materials tested, the green highlight under cumulative fluence shows the level after which a determination of NSD had been made.

Table 7. Appearance test results

Material	**Irradiance** ($\frac{mW}{cm^2}$)	**Cumulative Fluence** ($\frac{J}{cm^2}$)						**Exposed Sample**
AerForm LHR (Grey)	4.1	47	96	146				
Avionics Display Panel	4.2	68	137	182	238	305		

3 Conclusions

3.1 Ultraviolet disinfection

Ultraviolet (UV) disinfection testing was performed by five OEMs (Table 8). Testing varied by UV source, wavelength, and exposure amount. All UV testing summarized in this report had minimal or no effect on flight deck materials. OEM 1's Far-UV 222 nm verified material and component compatibility through testing, although the specific materials and components subjected to the tests were not disclosed. OEMs 3 and 4 conducted tests with approximately 254 nm UV-C light, and both reported no visible degradation after exposure. OEM 5 exposed materials to 1 MJ/m^2 of 254 nm UV-C light. The 1 MJ/m^2 dose resulted in slight color changes and a decrease in tear resistance. OEM 6 also conducted tests with 254 nm UV-C light, and continued exposure until slight discoloration occurred.

Table 8. UV testing results

OEM	**Max UV Dose**	**Materials Tested**	**Result**
OEM 1	Far-UV 222nm 3 mJ/cm^2	unknown	
OEM 3	UV-C 254nm 20 J/cm^2	pushbuttons, plastic guards, knobs, leather	

OEM	Max UV Dose	Materials Tested	Result
OEM 4	UV-C 253.7nm 20 J/cm^2	cockpit touchscreen display, cockpit instrument panels	
OEM 5	UV-C 254nm 1 MJ/m^2	wool/polyamide textiles, seatbelts, carpet	
OEM 6	UV-C 254nm 146 J/cm^2 305 J/cm^2	CPVC, avionics display panel	

No/negligible change

Minor change

3.2 Thermal disinfection

OEMs 1 and 5 tested thermal disinfection for efficacy against the virus and material compatibility. They both concluded that long-term high temperature exposure to materials and components is covered by component qualification. As long as thermal disinfection is performed with the airplane unpowered, all equipment is rated to withstand temperatures up to 85℃. The max operating temperature of the aircraft is 70ºC, while 85ºC is the max surviving temperature. Both OEMs exposed the flight deck to no more than 55℃. Table 9 shows the exposure time limits associated with the maximum temperature limits for aircraft components.

Table 9. Airplane thermal limits

	Operating	**Non-Operating (unpowered)**
Up to 60ºC	Indefinite exposure	
60 to 70ºC	No greater than 30 minutes	Indefinite exposure
70 to 85ºC	N/A	

3.3 Liquid disinfection

All OEMs conducted disinfection tests with a number of different liquid products and methods. Only testing conducted with IPA, Sani-Cide EX3, and Calla 1452 is comparable between OEMs.

OEM 1 and 2 conducted tests with different concentrations of IPA. OEM 1 used 70% IPA, while OEM 2 used a combination of 50% IPA and 50% de-ionized water. Both concluded that the IPA had negligible effects on materials. The CDC recommends 70% IPA for disinfection against SARS-CoV-2. OEM 2 made no guarantee regarding the effectiveness of their 50% IPA in disinfecting against SARS-CoV-2.

Sani-Cide EX3 was also tested by OEM 1 and 2, both reported significant degradation to materials and components. OEM 1 halted testing early after 16 applications due to operation failures and negative impacts on component surfaces. In OEM 2s testing, the optical test showed significant changes to the material after 10 exposures of Sani-Cide EX3.

Calla 1452 was tested with an electrostatic sprayer by OEM 1 and 5, with both reporting visual and functional consequences. Pooling of liquid and liquid intrusion into electronics caused significant degradation. These results are a byproduct of the electrostatic spray method, since OEM 1 also tested Calla 1452 with cloth application and noted minimal effect on materials.

Ozone, Vital Oxide, Diversey OxiVirTB, Ecolab Aperoxide Multi-surface, and M-Zone Wipes were only tested by OEM 2. Evaluation with optical and visual tests showed that these products all caused significant degradation to the material.

Hydrogen Peroxide (3%) was only tested by OEM 3 on cockpit dado panel paint. No effect was observed.

Peroxigard, which contains hydrogen peroxide as an active ingredient, was tested twice by OEM 1, first with a spray bottle and then with an electrostatic sprayer. The spray bottle method had minimal effects on material appearance, however the electrostatic sprayer did have negative impacts such as residue left on switches.

Netbiokem was only tested by OEM 5 with an electrostatic fogger, the testing resulted in significant visual and performance changes.

3.4 FAA operator survey

Thirty-one aircraft operators (airlines, OEMs, cargo companies, etc.) provided responses to the FAA operator survey, in which they provided information about the disinfecting procedures they implemented during the COVID-19 pandemic. Operators provided information about the disinfecting methods that were used, including: specific disinfectant product names, who performs the disinfection process, and how frequently the processes are performed. In summary, isopropanol was the most commonly used disinfectant product, but most operators used one of the other listed products. Wiping was reported as the method of application used by the majority of operators. The most commonly reported frequencies of disinfecting were daily, between each flight, or at each crew change. The summary report of this survey is available in Appendix G.

4 References

Chou, S., Overfelt, R., Gale, W., Gale, H., Shannon, C., & Buschle-Diller, G. (2009). *Effects of Hydrogen Peroxide on Common Aviation Textiles.* Auburn: FAA.

A Original equipment manufacturer 1 documents

May 21st, 2020

Subject: Flight Deck Disinfectant Bench Testing **Appendices:** Appendix A

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Background

In order to determine an appropriate disinfectant to use in the flight deck to remove contamination of COVID-19, bench testing was performed on various LRU (Line Replaceable Unit) equipment using the following disinfectants, selected based on conformance to D6-7127:

1. 70% IPA solution
2. Sani-Cide EX3 (Celeste Industries Corporation)
3. Calla 1452 (Zip Chem Aviation Products)

The tests were performed to assess for material compatibility, evaluated using color standards and gloss measurements.

Testing

70% IPA Experimentation

70% IPA testing was performed on 14 LRUs, belonging to different airplane models and ranging in color and configuration. The list of LRUs are in Table 1. Before testing started, half of each LRU was taped off to designate half the area for 70% IPA testing, with the other half designated for Sani-Cide EX3 testing. Initial conditions of all the LRUs were documented by taking pictures with color standards, and gloss measurements for LRUs with a flat surface area.

Table 1: List of Tested LRUs

#	Description	Model
1	Display Unit	[redacted]
2	Cursor Control Device (CCD)	[redacted]
3	EFIS Control Panel	[redacted]
4	Cursor Control Device (CCD)	[redacted]
5	Parking Brake Assy	[redacted]
6	Multifunction Keypad (MKP)	[redacted]
7	Flap Module Assy	[redacted]
8	Display Unit	[redacted]
9	Display Control Panel (DCP)	[redacted]
10	Clock / Mic	[redacted]
11	Audio Control Panel (ACP)	[redacted]
12	Gage Number Clicker	[redacted]
13	A/P Switch	[redacted]
14	WXR Panel	[redacted]

The procedure for 70% IPA testing was as follows:

1. Saturated [redacted] cloth with 70% IPA
2. Wiped designated surfaces of LRUs, and maintained surfaces wet for 10-12 minutes
3. Wiped surfaces dry at the end of the 10-12 minute dwell time
4. Allowed a minimum of 2 hours for surfaces to dry
5. After 2 hours, pictures were taken with color standards, gloss measurements were recorded and LRUs were observed for any damage
6. Repeated steps 1-5 until 20 applications were completed

Sani-Cide EX3 Experimentation

Sani-Cide EX3 testing was performed on the other half of the same LRUs listed in Table 1, except item number 5, because it could not be divided into two sections. Similar to 70% IPA testing, initial conditions of the LRUs were documented with pictures and color standards, and initial gloss measurements were recorded on LRUs with a flat surface area. The procedure for Sani-Cide EX3 testing was as follows:

1. Sprayed LRU surfaces with Sani-Cide EX3 using manufacturer's spray bottle until all surfaces were wet (avoided pooling liquid when possible)
2. Maintained surfaces wet for 10-12 minutes
3. Wiped surfaces dry with [redacted] cloth
4. Allowed 10-15 minutes for surfaces to dry
5. Repeated steps 1-4 until 20 applications were completed
6. Pictures with color standards and gloss measurements were taken after every 10 applications

Calla 1452 Experimentation

Calla 1452 testing was performed on eight LRUs, listed in Table 2. The same half of each LRU that was used for 70% IPA testing was also used for Calla 1452 once all 70% IPA testing was completed. The LRUs that were chosen to be tested did not have any significant initial appearance defects and functioned properly. At least one LRU was chosen from each of the three airplane models to be able to test the different color schemes. Pictures documenting initial conditions and pictures with color standards were taken before testing began, along with initial gloss measurements of LRUs with a flat surface area.

Table 2: List of Calla 1452 Tested LRUs

#	Description	Model
1	Cursor Control Device (CCD)	[redacted]
2	Cursor Control Device (CCD)	[redacted]
3	Parking Brake Assy	[redacted]
4	Flap Module Assy	[redacted]
5	Display Control Panel (DCP)	[redacted]
6	Clock / Mic	[redacted]
7	Gage Number Clicker	[redacted]
8	A/P Switch	[redacted]

The procedure for Calla 1452 testing was similar to 70% IPA, as follows:

1. Saturated [redacted] cloth with Calla 1452
2. Wiped designated surfaces of LRUs, and maintained surfaces wet for 10-12 minutes
3. Wiped surfaces dry at the end of the 10-12 minute dwell time
4. Allowed a minimum of 2 hours for surfaces to dry
5. After 2 hours, pictures were taken with color standards, gloss measurements recorded and observed for any damage
6. Repeated steps 1-5 until 20 applications were completed

Results

70% IPA Results

The gloss measurements recorded for LRUs tested with 70% IPA are shown in Table 3. Based on coefficient of variation results, the change in gloss appearance on all LRUs tested were negligible after a total of 20 cycles. There are no consistent trends between gloss measurement results of LRUs with similar color schemes. A comparison of initial and after testing pictures for each color scheme is shown in Figure 1 through Figure 4. Note that due to lighting, the colors between pictures may appear different. It is more important to compare the coatings of the LRUs to the color standards.

Table 3: 70% IPA Testing – Gloss Measurement Results

Color Scheme	[redacted]						[redacted]		[redacted]
Cycle #	**Display**	**DCP**	**CCD**	**Brake Assy**	**MKP**	**Flap Assy**	**CCD**	**Display**	**EFIS**
Initial	0.7	0.2	0.5	0.3	0.2	0.2	0.3	0.1	0.2
1	0.3	0.2	0.1	0.3	0.2	0.2	0.2	0.4	0.3
2	0.3	0.2	0.1	0.2	0.4	0.2	0.2	0.2	0.2
3	0.4	0.2	0.2	0.3	0.4	0.2	0.2	0.5	0.3
4	0.3	0.2	0.1	0.5	0.2	0.2	0.2	0.4	0.5
5	0.3	0.3	0.4	0.1	0.2	0.2	0.2	0.5	0.3
6	0.3	0.4	0.1	0.4	0.2	0.3	0.2	0.3	0.4
7	0.3	0.3	0.1	0.1	0.2	0.2	0.2	0.5	0.5
8	0.3	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.2
9	0.3	0.4	0.2	0.1	0.3	0.2	0.2	0.4	0.4
10	0.3	0.3	0.1	0.1	0.2	0.2	0.3	0.4	0.4
11	0.4	0.2	0.1	0.1	0.2	0.2	0.2	0.4	0.2
12*	-	-	-	-	-	-	-	-	-
13	0.4	0.2	0.1	0.1	0.2	0.2	0.2	0.5	0.4
14	0.3	0.4	0.1	0.1	0.2	0.2	0.4	0.4	0.7
15	0.3	0.5	0.1	0.1	0.2	0.3	0.2	0.4	0.6
16	0.4	0.2	0.1	0.1	0.2	0.2	0.2	0.4	0.5
17	0.3	0.5	0.1	0.1	0.2	0.3	0.3	0.6	0.5
18	0.4	0.2	0.1	0.1	0.2	0.3	0.3	0.5	0.5
19	0.3	0.2	0.1	0.1	0.2	0.2	0.1	0.5	0.4
20	0.3	0.1	0.1	0.1	0.2	0.2	0.5	0.4	0.4
CV	0.27	0.45	0.76	0.72	0.28	0.19	0.37	0.27	0.35

*Gloss measurements were not performed after cycle 12.

Figure 1: [redacted] **gray color scheme; initial (left), after 20 cycles of 70% IPA (right)**

Figure 2: [redacted] **brown color scheme; initial (left), after 20 cycles of 70% IPA (right)**

Figure 3: [redacted] **gray color scheme; initial (left), after 20 cycles of 70% IPA (right)**

Figure 4: [redacted] **black color scheme; initial (left), after 20 cycles of 70% IPA (right)**

Sani-Cide EX3 Results

The gloss measurements recorded for LRUs tested with Sani-Cide EX3 are shown in Table 4. Gloss measurements were only taken after every 10 cycles, because minimal changes were expected between each cycle. After each application, it was found that Sani-Cide EX3 left behind sticky residue and streaks of dried liquid on the surface of the LRUs even after they were wiped dry. An example from testing in a [redacted] flight deck is shown in Figure 5.

Figure 5: Example of sticky residue and streaks of dried Sani-Cide EX3 on surfaces from testing in a [redacted] flight deck

(Figure is not of equipment tested per the procedure of this report)

Testing with Sani-Cide EX3 was suspended after cycle 16, due to primer adhesion failure seen on the [redacted] flap module assembly. Pictures of this failure can be seen in Appendix A (see SR17024 for additional details). When function checks were performed after 16 cycles, several issues were found, including a halo effect on the [redacted] display, variance in backlight brightness in the [redacted] MKP and contrast issues in the display of the [redacted] WXR Panel. These issues can potentially be caused by the spraying application method of Sani-Cide EX3. The spraying method applied a volume of liquid sufficient for formation of pooling liquid. These pools led to liquid ingress, exposing the electrical components to the liquid for an extended period of time. Images of all these issues can be found in Appendix A. Since the test was suspended early, there is not a sufficient amount of gloss measurement data points available to form conclusions on the effects of Sani-Cide EX3 on the coating of the LRUs. A comparison of initial and after testing pictures for each color scheme is shown in Figure 6 through Figure 9.

Table 4: Sani-Cide EX3 Testing – Gloss Measurement Results

Color Scheme	[redacted]					[redacted]		[redacted]
Cycle #	**Display**	**MFD**	**CCD**	**MKP**	**Flap Assy**	**CCD**	**Display**	**EFIS**
Initial	0.7	0.2	0.5	0.2	0.2	0.3	0.1	0.2
10	0.3	0.3	0.1	0.4	0.2	0.2	0.4	0.2
20	-	-	-	-	-	-	-	-
CV	0.57	0.28	0.94	0.47	0.00	0.28	0.85	0.00

Figure 6: [redacted] gray color scheme; initial (left), after 16 cycles of Sani-Cide EX3 (right)

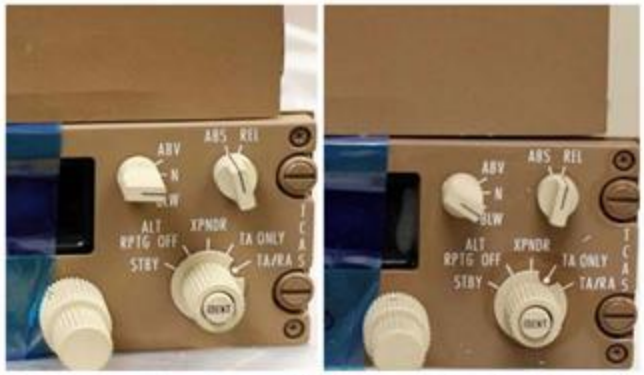

Figure 7: [redacted] brown color scheme; initial (left), after 16 cycles of Sani-Cide EX3 (right)

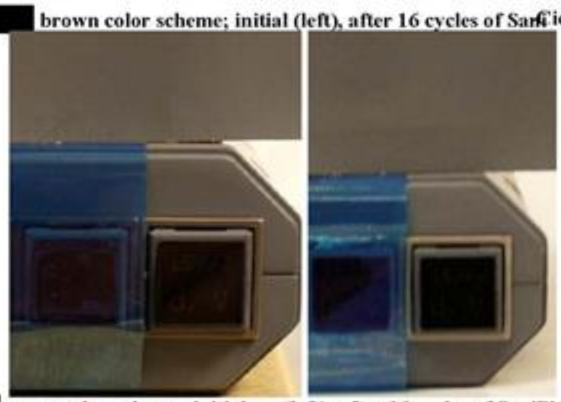

Figure 8: [redacted] gray color scheme; initial (left), after 16 cycles of Sani-Cide EX3 (right)

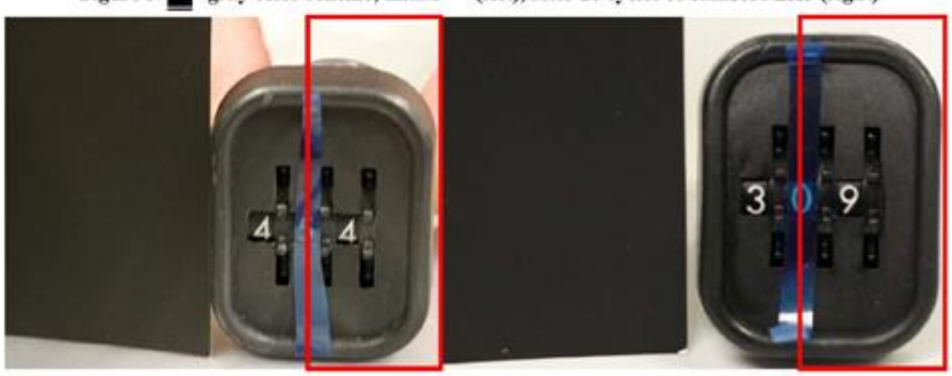

Figure 9: [redacted] black color scheme; initial (left), after 16 cycles of Sani-Cide EX3 (right)

Calla 1452 Results

The recorded gloss measurements of LRUs tested with Calla 1452 are shown in Table 5. Based on the coefficient of variation (CV), the change in gloss of the coating of the LRUs were minimal throughout the 20 cycles of testing. The pictures taken with color standards after each cycle also showed no changes in appearance. A comparison of initial and after testing pictures for each color scheme is shown in Figure 10 through Figure 13.

Table 5: Calla 1452 Testing – Gloss Measurement Results

Color Scheme	[redacted] [redacted]				[redacted]
Cycle #	**MFD**	**CCD**	**Brake Handle**	**Flap Handle**	**CCD**
Initial	0.1	0.1	0.1	0.2	0.5
1	0.5	0.1	0.3	0.2	0.1
2	0.2	0.2	0.3	0.2	0.4
3	0.4	0.1	0.3	0.2	0.2
4	0.3	0.2	0.2	0.4	0.1
5	0.2	0.1	0.1	0.2	0.2
6	0.2	0.1	0.1	0.2	0.3
7	0.3	0.2	0.2	0.2	0.3
8	0.3	0.2	0.1	0.2	0.3
9	0.1	0.1	0.2	0.2	0.3
10	0.2	0.2	0.1	0.2	0.3
11	0.3	0.1	0.4	0.2	0.2
12	0.2	0.1	0.1	0.2	0.3
13	0.2	0.1	0.3	0.2	0.2
14	0.3	0.1	0.1	0.3	0.3
15	0.1	0.1	0.1	0.2	0.3
16	0.3	0.1	0.4	0.2	0.2
17	0.2	0.1	0.2	0.2	0.2
18	0.3	0.1	0.1	0.2	0.3
19	0.2	0.1	0.1	0.2	0.3
20	0.4	0.2	0.1	0.2	0.3
CV	0.41	0.36	0.57	0.22	0.34

Figure 10: [redacted] **gray color scheme; initial (left), after 20 cycles of Calla 1452 (right)**

Figure 11: [redacted] **brown color scheme; initial (left), after 20 cycles of Calla 1452 (right)**

Figure 12: [redacted] **gray color scheme; initial (left), after 20 cycles of Calla 1452 (right)**

Figure 13: [redacted] **black color scheme; initial (left), after 20 cycles of Calla 1452 (right)**

Conclusion

Due to the amount of liquid applied, the spray bottle application method caused areas of pooling liquid, leading to liquid ingress that may lead to equipment functionality issues or primer adhesion failure as seen in the results of this report. The wipe application method applies a sufficient amount of liquid to wet the surfaces of the LRUs without creating areas of pooling liquid.

Appendix A

Figure A-1: Primer adhesion failure on flap module assembly due to Sani-Cide EX3 dripping down the side of the assembly (see SR17024 for additional details)

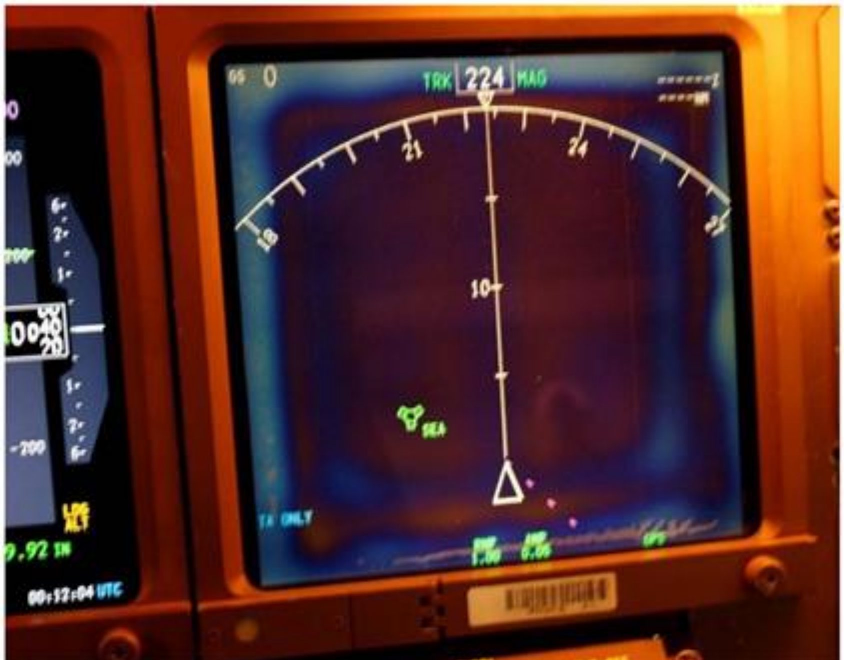

Figure A-2: Halo effect on [redacted] display

Figure A-3: Variance in backlight brightness in [redacted] MKP (buttons with blue tint were covered with blue flash tape)

Figure A-4: Contrast issues in [redacted] WXR panel display (display should read "0333")

June 16th, 2020
SR 17044

Subject: Peroxigard Flight Deck Disinfectant Bench Testing

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Background

Peroxigard, manufactured by Virox Technologies, is being evaluated as a potential disinfectant for use in the flight deck to remove contamination of COVID-19. Bench testing was performed to evaluate for material compatibility with various flight deck hardware. The tested hardware was compared to baseline hardware, and when applicable, color standards and gloss measurements.

Testing

Testing of Peroxigard was performed on a parking brake assembly and seven (7) knobs of various color schemes. The initial conditions of all tested items were documented by pictures with the baseline hardware and applicable color standard. Gloss measurements were only taken for the parking brake assembly, due to the availability of a flat surface area. The procedure for Peroxigard testing was as follows:

1. Sprayed surfaces with Peroxigard using a spray bottle 6-8 inches from surface until all surfaces were wet (avoided pooling liquid when possible)
2. Maintained surfaces wet for 1 minute
3. Wiped surfaces dry with [redacted] cloth
4. Allowed a minimum of 10 minutes for surfaces to dry
5. Repeated steps 1-4 until 50 applications were completed
6. Pictures with baseline hardware and applicable color standard, and gloss measurements were taken after every 5 applications

Results

The gloss measurements recorded for the brake assembly tested with Peroxigard are shown in Table 1. Gloss measurements and pictures were only taken after every 5 cycles, because minimal changes were expected between each cycle. The gloss measurement results show that 50 applications of Peroxigard did not affect the gloss appearance of the brake assembly.

A comparison of pictures before and after testing for each piece of hardware is shown in Figure 1 through Figure 8. Note that due to lighting, the colors between the initial and after pictures may appear different. It is more important to compare the color of the coating to the color standards or baseline hardware within the pictures. In general, these pictures show that 50 applications of Peroxigard did not adversely affect the coating appearance of the hardware. However, it can be seen in Figure 9 that the Peroxigard did cause smearing of the paint used in the recessed labeling of the knobs. This paint smearing occurred after 14 applications of Peroxigard, but did not progressively get worse between applications 14 and 50. The other three knobs with recessed labeling did not experience smearing of the paint.

Table 1: Peroxigard Testing Gloss Measurement Results

Cycle #	[redacted] Brake Assy
Initial	0.3
1-5	0.2
6-10	0.2
11-15	0.2
16-20	0.1
21-25	0.2
26-30	0.2
31-35	0.2
36-40	0.1
41-45	0.1
46-50	0.1
CV	0.37

Figure 1: [redacted] **parking brake assembly; initial (left), after 50 cycles of Peroxigard (right)**

Figure 2: Gray "speed brake" knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 3: Tan numbered knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 4: Tan blank knob; initial (left), after 50 cycles of Peroxigard (right)

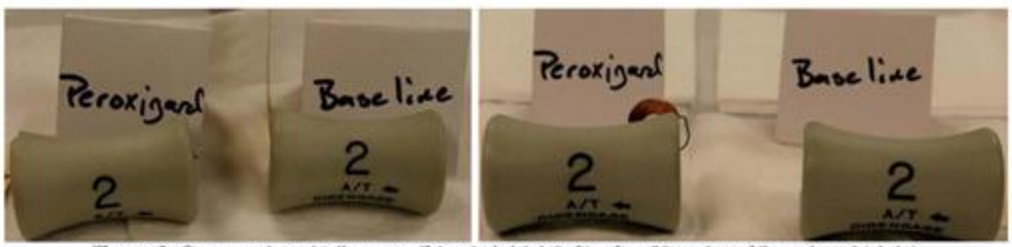

Figure 5: Gray numbered "disengage" knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 6: Gray "flap" knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 7: Gray blank knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 8: Gray numbered knob; initial (left), after 50 cycles of Peroxigard (right)

Figure 9: Smearing of paint in recessed labeling of knobs

Conclusions

The results presented in this report show that Peroxigard does not adversely affect the appearance of the parking brake assembly or the various knobs used in the flight deck. However, 14 applications of Peroxigard did cause the paint used in the recessed labeling of the knobs to smear. However, the smearing did not progressively get worse between applications 14 and 50, and the smearing only occurred on two out of the five tested knobs with recessed labeling.

August 17th, 2020

Subject: Flight Deck Disinfectant Testing in [redacted] Engineering Cab by Electrostatic Spraying

References: SR 17029, "Flight Deck Disinfectant Bench Testing"

SR 17044, "Peroxigard Flight Deck Disinfectant Bench Testing"

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Background

Calla 1452, manufactured by Zip Chem Aviation Products, and Peroxigard, manufactured by Virox Technologies, are being evaluated for use as a disinfectant in the flight deck to remove contamination of COVID-19. Bench testing was completed for Calla 1452 and Peroxigard, showing promising results (refer to SR17029 and SR17044, respectively). The next step of testing was to evaluate the feasibility of application in the flight deck, ensuring that surfaces are able to stay wet for the minimum amount of time required to disinfect the surfaces without ingress that may potentially affect the functionality of the LRUs (Line Replaceable Unit).

Testing

The testing of Calla 1452 and Peroxigard for feasibility was performed in the [redacted] engineering cab, which is a representative flight deck. An electrostatic sprayer (e-spray) from Electrostatic Spraying Systems (ESS), model SC-MB was used as the method of application, applying drop sizes of 40 µm with a nominal liquid flow rate of 1 gallon per hour (~63 mL per minute). Multiple intermittent passes (maximum of 4) were allowed to maintain surfaces wet for the required dwell time. Liquid pooling and dripping was avoided when possible. The areas tested in the [redacted] engineering cab were the first officer's side, the overhead panels and the aisle stand, as shown in Figure 1 and Figure 2. All displays were masked and not subjected to the disinfectants. Liquid indicator tape was applied to the internal perimeter of all tested LRUs to indicate liquid ingress. The tape is designed to be white when dry and permanently turns red when it has been wetted. After testing of both disinfectants were complete, LRUs which exhibited functional issues were disassembled and evaluated for fluid ingress and corrosion.

The sequence of testing in the [redacted] engineering cab was completed as follows: 10 applications of Calla 1452, 20 applications of Peroxigard, then an additional 10 applications of Calla 1452 to achieve the total of 20 applications. In this test, an application is defined as a set of spraying which consisted of 1 – 4 coats of disinfectant depending on the application.

The test procedure for Calla 1452 was as outlined below. The number of coats applied for each application is in Table 1.

1. Applied a coat of Calla 1452 on all LRUs using e-sprayer (dripping and pooling avoided when possible)
2. If another coat was applied (per Table 1), wait 40 seconds then applied the next coat
3. Repeated step 2 as necessary (per Table 1), avoiding dripping and pooling when possible

4. Wiped surfaces dry with [redacted] cloth at the end of the 10-12 minute dwell time
5. Allowed a minimum of 1 hour for surfaces to dry
6. During the 1 hour dry time, inspection of the liquid indicator tape was performed to check for liquid ingress
7. Repeated steps 1-5 until 20 applications were completed
8. Function checks of the engineering cab were performed at the end of each day (Table 1) **Table 1: Number of coats applied for each Calla 1452 application**

Baseline function check	
Application #1	Single coat
Function check	
Application #2	Two coats
Function check	
Application #3	Two coats
Function check	
Application #4	Three coats
Function check	
Application #5	Four coats
Function check	
Application #6	Single coat
Application #7	Two coats
Application #8	Two coats
Function check	
Application #9	Two coats
Application #10	Two coats
Function check	
Application #11	Two coats
Application #12	Two coats
Application #13	Two coats
Application #14	Three coats
Application #15	Three coats
Function check	
Application #16	Two coats
Application #17	Two coats
Application #18	Two coats
Application #19	Two coats
Application #20	Two coats
Final function check	

The test procedure for Peroxigard was as follows:

1. Applied a coat of Peroxigard on all LRUs using e-sprayer (dripping and pooling avoided when possible)
2. If several surfaces dried prior to the 1 minute dwell time, another coat was applied
3. Wiped surfaces dry with [redacted] at the end of the 1 minute dwell time
4. Allowed a minimum of 30 minutes for surfaces to dry
5. During the 30 minute dry time, inspection of the liquid indicator tape was performed to check for liquid ingress
6. Repeated steps 1-4 until 20 applications were completed
7. Function checks of the engineering cab were performed at the end of each day (Table 2)

Table 2: Schedule of function checks

Baseline function check
Application #1
Application #2
Function check
Application #3
Application #4
Application #5
Application #6
Application #7
Application #8
Application #9
Function check
Application #10
Application #11
Application #12
Application #13
Application #14
Application #15
Function check
Application #16
Application #17
Application #18
Application #19
Application #20
Final function check

Figure 1: Overheard LRUs subjected to e-spray (three buttons in top left are not considered LRUs). Liquid indicator tape was applied only to LRUs in the red box.

Figure 2: LRUs subjected to e-spray (LRUs under red line were not e-sprayed)

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Calla 1452 Results

Liquid ingress was not seen on any of the LRUs until four (4) coats of Calla 1452 were applied within one 10 minute dwell time with 40 seconds between each coat. 40 seconds was set as the time between each coat because this was recorded as the approximate time at which some dry surfaces were observed after spraying. The most significant ingress after four (4) coats of Calla 1452 was observed under the light plates of the control stand assembly (254W1100), indicated by the red spots on the tape in Figure 3. Liquid dripping was also observed on the overhead panels as seen in Figure 4. Based on this result, four coats were determined to be the maximum number of coats that can be applied in the engineering cab.

The results of the function check performed after 10 applications of Calla 1452 (before Peroxigard testing) showed the following. Refer to ITRACS item number listed in Table 3 for a more detailed report of each function check's results. •

Left audio control panel:

○ "L VHF" button stuck in the pressed position and required four presses to function ○ "MIC" switch was stuck and had the "RADIO TRANSMIT" messages displayed

- Fuel system module assembly lights were dimmed
- Transponder would not go into standby

The results of the final function check performed after 20 applications of Calla 1452 showed the following.

- Fuel system module assembly lights were dimmed
- Transponder would not go into standby

Table 3: Sequence of Calla 1452 function checks

Baseline function check	
Application #1	Single coat
Function check	
Application #2	Two coats
Function check	
Application #3	Two coats
Function check	
Application #4	Three coats
Function check	
Application #5	Four coats
Function check	

Application #6	Single coat
Application #7	Two coats
Application #8	Two coats
Function check	
Application #9	Two coats
Application #10	Two coats
Function check	
Application #11	Two coats
Application #12	Two coats
Application #13	Two coats
Application #14	Three coats
Application #15	Three coats
Function check	
Application #16	Two coats
Application #17	Two coats
Application #18	Two coats
Application #19	Two coats
Application #20	Two coats
Final function check	

Figure 3: Largest amount of liquid ingress (indicated by red spots) under the light plates of the control stand assembly

Figure 4: Liquid dripping on overhead panels after 4 coats of Calla 1452

Peroxigard Results

In order to maintain LRU surfaces wet with Peroxigard for the 1 minute dwell time, 1-2 coats needed to be applied. The number of coats applied depended on how quickly the surfaces dried during the 1 minute dwell time. Since the glare shield LRU surfaces were the quickest to dry, these surfaces were sprayed with a second coat after 20 seconds had elapsed in application 12 – application 20. No indications of liquid ingress were observed on any of the LRUs throughout the 20 applications. The results of the final function check, performed after 20 applications of Peroxigard revealed the following.

Refer to the ITRACS item number listed in Table 4 for a more detailed report of each function check's results.

- First officer's audio control panel:
  - SAT L "MIC" light indicator burned out or was non-functional
  - L "SATCOM" light was non-functional o Switches were sticky due to Peroxigard residue
- Fuel system module assembly arm light was non-functional
- Residue left on the windows reduced visibility (windows are plastic and not representative of aircraft windows)

Table 4: Sequence of Peroxigard function checks and ITRACS item number

Baseline function check
Application #1
Application #2
Function check
Application #3
Application #4
Application #5

Application #6
Application #7
Application #8
Application #9
Function check
Application #10
Application #11
Application #12
Application #13
Application #14
Application #15
Function check
Application #16
Application #17
Application #18
Application #19
Application #20
Final function check

Teardown Results

The first officer's ACP that exhibited functional issues was disassembled and evaluated for ingress and corrosion. The components in Figure 5 through Figure 7 did not show any signs of ingress or corrosion. However, there was an accumulation of foreign object debris (FOD) and residue around the "MIC CALL" buttons that likely caused the buttons to be stuck in the "pushed" position and required several press attempts to function. Since this equipment has been in the [redacted] engineering cab prior to when flight deck disinfection testing started, it is unknown if the functional issues were due to the disinfectant residue, or accumulation of FOD over time, or both.

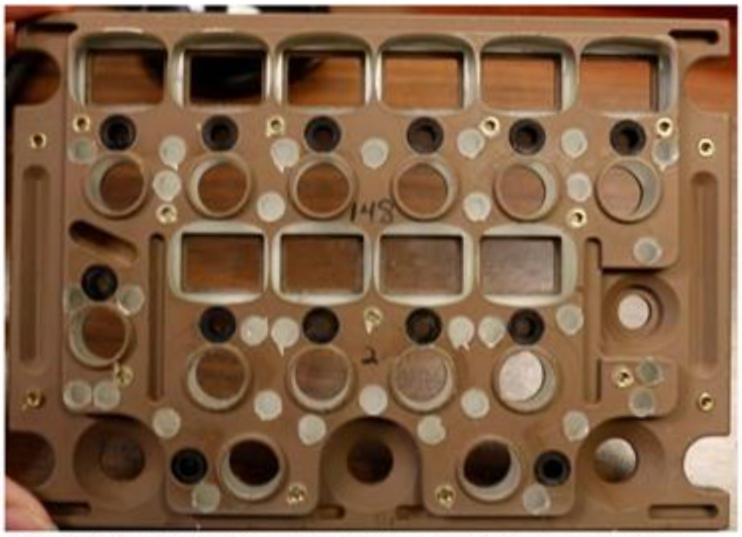

Figure 5: Back of ACP light plate showing no signs of ingress or corrosion

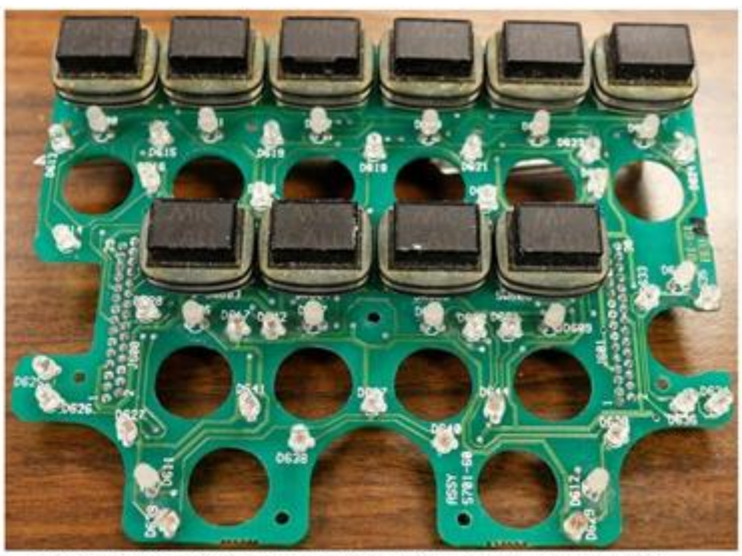

Figure 6: ACP circuit board showing no signs of ingress or corrosion

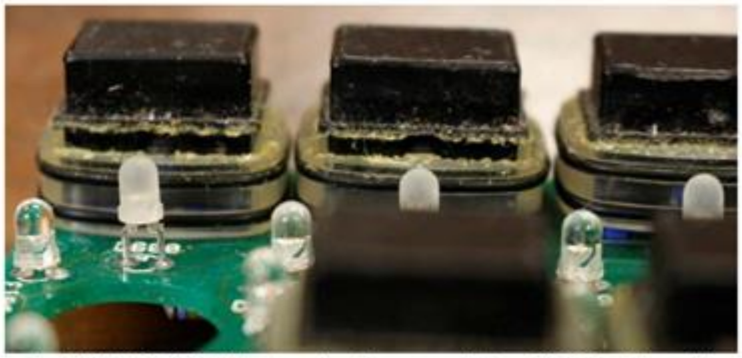

Figure 7: ACP "MIC CALL" buttons showing accumulation of FOD / sticky residue

Conclusions

Due to the 10 minute wet dwell time of Calla 1452 in order to disinfect surfaces, application by espray was not a feasible method of disinfecting the flight deck. The number of sprays that were required to maintain surfaces wet for 10 minutes would cause significant pooling and dripping that may cause damage to the LRUs. However, the amount of Calla 1452 that could be applied by e-spray were adequate for cleaning of the flight deck instead. For Peroxigard, the short 1 minute wet dwell time allowed the appropriate number of sprays to occur in order to disinfect the flight deck without causing pooling and dripping. However, e-spray testing performed on various coupons (bare aluminum, painted aluminum, carpet, etc.) performed separately showed detrimental effects such as corrosion and peeling / bubbling of paint.

August 20, 2020

Subject: Flight Deck Disinfectant Durability Exposure Testing

References: SR 17029, "Flight Deck Disinfectant Bench Testing"
SR 17067, "Flight Deck Disinfectant Testing in [redacted] Engineering Cab by Electrostatic Spraying"

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Summary

To extend operator allowance to use Calla 1452 applied by electrostatic sprayers in the Flight Deck beyond MOM-MOM-20-0053R7, a progressive severity exposure test was performed on a selection of flight deck equipment. Equipment was evaluated for fluid ingress, corrosion, and functional utility. Results indicated that corrosion was likely to begin after 90 applications and functional performance was likely to be degraded after 130 applications.

Background

Airline operators expressed a desire to use Calla 1452, an approved disinfectant per BSS7434, as a routine flight deck disinfectant. Calla 1452, manufactured by Zip Chem Aviation Products, was evaluated for use as a disinfectant in the flight deck to remove contamination of COVID-19. Two phases of testing were completed with promising results, including bench testing (SR 17029) and electrostatic spray (e-spray) testing in a representative flight deck ([redacted]). As a result, a multi-operator memo was released providing no technical objection to cleaning of flight decks with Calla 1452 using an espray under the following conditions: 1) spraying could not result in pooling, drips, or rivulets; 2) no more than two passes on each piece of equipment were permitted per cleaning, and at least two minutes must have elapsed between the passes; 3) such cleaning could not be performed more frequently than monthly and for no more than 12 months; 4) certain items, including seat belts and main displays, could not be cleaned except per component maintenance manual. The next step of testing was to evaluate the durability of LRUs (Line Replaceable Unit) in the flight deck after increased exposure to Calla 1452.

Testing

The durability exposure testing of Calla 1452 was performed on the most susceptible LRUs between the [redacted] flight decks, as selected based on the results of Phase I and Phase II testing by flight deck engineers who were familiar with the LRUs. The LRUs selected and tested are listed in Table 1. Prior to the start of testing, a function check and thorough pictures were taken of all LRUs to document the as-received condition of the equipment.

Table 1: List of Tested LRUs

#	Description	Model
1	Audio Control Panel (ACP)	[redacted]
2	P5-13 Electric Meters, Battery and Galley Power Panel	
3	P5-6 Cabin Pressure Selector Panel	
4	PR-2 Fuel Control Panel	
5	Cabin Altimeter - Differential Pressure Indicator	
6	Mode Control Panel (MCP)	
7	Alerting and Transponder Control	[redacted]
8	Multifunction Keypad (MKP)	
9	Audio Control Panel (ACP)	
10	Tuning and Control Panel (TCP)	
11	Display Control Panel (DCP)	

Since it was previously determined in Phase II of testing that Calla 1452 cannot be used to disinfect LRU surfaces due to the 10 minute wet dwell disinfection time potentially resulting in fluid ingress, the goal of the long term testing was to use Calla 1452 as a cleaning agent. For all applications, multiple sprays were applied to maintain surfaces wet as long as possible while avoiding liquid pooling and dripping. Liquid indicator tape was applied to the internal perimeter of all tested LRUs to indicate liquid ingress. After a pre-determined number of applications were applied, function checks and disassembly were performed on all LRUs to evaluate for ingress and corrosion.

Anticipating operator requests to increase the frequency of e-spray disinfection and to extend the number of unobjectionable e-spray applications, the number of cumulative cleaning applications was set at 360, representing approximately one year of daily applications or more than one airplane life of monthly applications. Previous testing revealed that fluid ingress was a major contributor to equipment functional issues, therefore a progressive severity test was employed. Each phase of testing was intended to result in more wetting than the previous test phase, while taking care to avoid pooling, rivulets, and dripping. Variables altered between phases included the traverse speed of the e-spray nozzle, the number of e-spray passes per application, the time delay between the end of the last e-spray pass of one application and the start of the next application, and the number of applications per phase.

In order to minimize the variability of application within each test phase, a robot was employed to consistently apply Calla 1452 in each test phase after Phase III.1. A video recording of a skilled technician applying Calla 1452 during Phase III.1 was used to establish the robotic e-sprayer parameters used in subsequent testing.

Phase III.1

The [redacted] LRUs listed in Table 1 were installed and tested in the [redacted] engineering cab (Figure 1). The [redacted] LRUs were installed and tested on test fixtures representative of the flight deck configuration (Figure 2). Manual spray applications were performed in sets of 1, 2, 3 and 4 applications with the order of sets randomized, for a total of 10

applications. Function checks and disassembly were performed only after all applications in each set were completed. Each application of Calla 1452 was performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs (dripping and pooling avoided when possible)
2. Waited 2-3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs (dripping and pooling avoided when possible)
4. Waited 10 minutes, then wiped surfaces dry with [redacted] cloth
5. If in the middle of a set, waited 50 minutes then repeated Steps 1-4
6. If at the end of a set, LRUs were function checked immediately in respective engineering cabs (within 30 minutes)
   a. Disassembly was performed after each function check to evaluate the extent of any fluid intrusion and detect evidence of corrosion

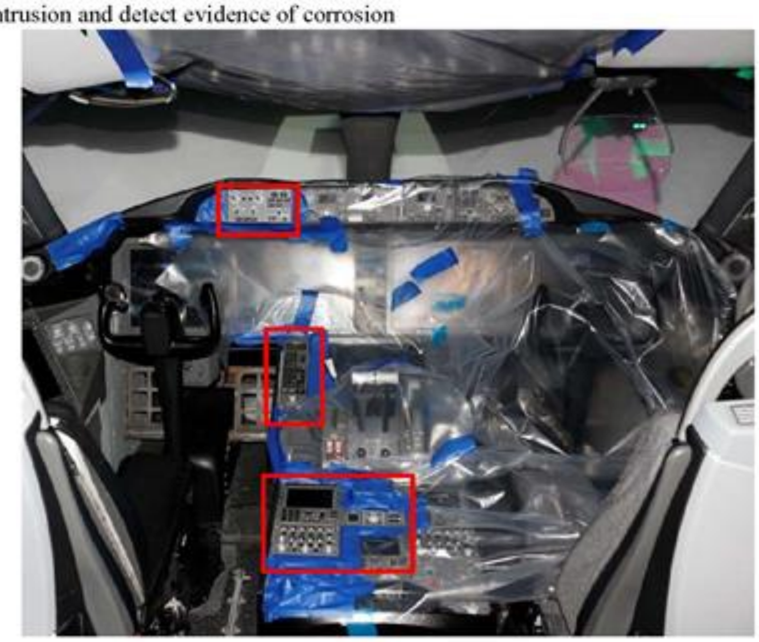

Figure 1: LRUs installed in [redacted] CAB

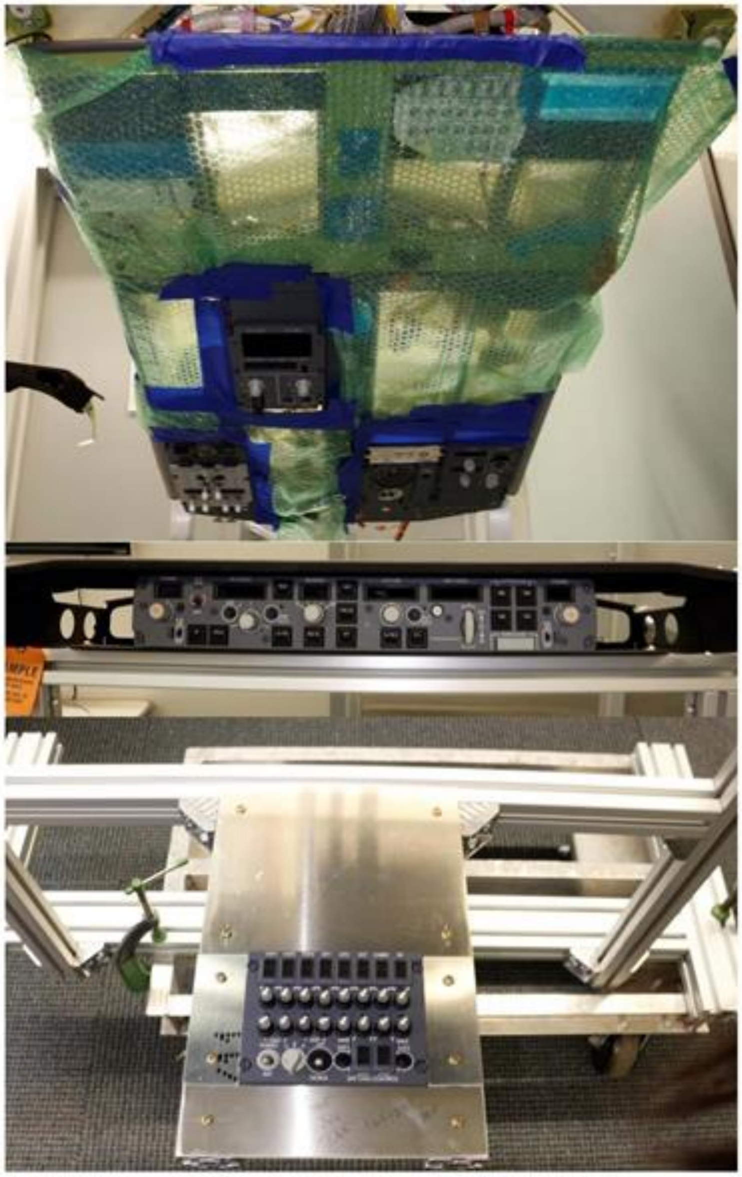

Figure 2: LRUs installed on [redacted] Phase III.1 test fixtures

Phase III.2

All LRUs for this phase of testing were installed and sprayed in a test fixture representative of the flight deck configuration. To maintain consistency for all applications, the e-spray was performed using a Kuka robot. The setup is shown in Figure 3. Function checks and disassembly were performed after a total of 20 cleaning applications were conducted. Each application of Calla 1452 was performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity
   a. Sprayed all LRUs using a nominal spray line velocity of 38 inches per second and nozzle distance of 18 – 24 inches
      - Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal
      - Glare shield LRUs: Single right/left pass normal to LRU surfaces
      - [redacted] MKP: Single up/down pass normal to surface
      - Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal
2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 1 hour
5. Repeated steps 1 – 4 until 20 applications were completed
6. Disassembly of LRUs
7. Performed function check of all LRUs

Figure 3: Setup of Calla 1452 e-spray testing using Kuka robot

Phase III.3

The setup of this testing was similar to the setup in Phase III.2, except for a decrease in the linear spray velocity on all LRUs (except the MKP) in order to generate more ingress. A total of 20 applications were performed. Each application of Calla 1452 was performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity

a. Sprayed all LRUs with nozzle distance of 18 – 24 inches

- Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal with linear spray velocity of 25 inches per second
- Glare shield LRUs: Single right/left pass normal to LRU surfaces with linear spray velocity of 25 inches per second
- [redacted] MKP: Single up/down pass normal to surface with linear spray velocity of 38 inches per second
- Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal with linear spray velocity of 25 inches per second

2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 1 hour
5. Repeated steps 1 – 4 until 20 applications were completed
6. Disassembly of LRUs
7. Performed function check of all LRUs

Phase III.4

The setup of this testing was similar to that of Phase III.3, except a third coat was applied on all LRUs using a linear spray velocity of 38 inches per second. A total of 40 applications were performed. Each application of Calla 1452 was intended to be performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity

   a. Sprayed all LRUs with nozzle distance of 18 – 24 inches

   - Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal with linear spray velocity of 25 inches per second
   - Glare shield LRUs: Single right/left pass normal to LRU surfaces with linear spray velocity of 25 inches per second
   - [redacted] MKP: Single up/down pass normal to surface with linear spray velocity of 38 inches per second
   - Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal with linear spray velocity of 25 inches per second

2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 3 minutes
5. Sprayed a third coat of Calla 1452 on all LRUs per step 1, except with linear spray velocity of 38 inches per second for all LRUs
6. Waited 53 minutes (1 hour total from start of spray)
7. Repeated steps 1 – 6 until 20 applications were completed
8. Visually examined LRUs, test fixtures, robot and Calla 1452 reservoir level (top off when required)
9. Repeated steps 1 – 8 (for 40 total applications)

10. Performed function check of all LRUs
11. Disassembly of LRUs

After 6 applications were applied, the Kuka robot malfunctioned and discharged the remainder of the Calla 1452 reservoir onto the lower right corner of the fuel control panel. The procedure that actually occurred was as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity
   a. Sprayed all LRUs with nozzle distance of 18 – 24 inches
      - Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal with linear spray velocity of 25 inches per second
      - Glare shield LRUs: Single right/left pass normal to LRU surfaces with linear spray velocity of 25 inches per second
      - [redacted] MKP: Single up/down pass normal to surface with linear spray velocity of 38 inches per second
      - Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal with linear spray velocity of 25 inches per second
2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 3 minutes
5. Sprayed a third coat of Calla 1452 on all LRUs per step 1, except with linear spray velocity of 38 inches per second for all LRUs
6. Waited 53 minutes (1 hour total from start of spray)
7. Repeated steps 1 – 6 until 6 applications were completed
8. Sprayed and discharged remainder of Calla 1452 reservoir onto lower right corner of fuel control panel
9. Refilled reservoir, and performed RCCA on Kuka robot
10. Repeated steps 1 – 6 until 14 applications were completed (20 total)
11. Visually examined LRUs, test fixtures, robot and Calla 1452 reservoir level (refilled when required)
12. Repeated steps 1 – 6 until 20 applications were completed (40 total)
13. Performed function check of all LRUs
14. Disassembly of LRUs

Phase III.5

Due to the Kuka robot failure, setup and procedure for Phase III.5 testing was identical to that of Phase III.4 as originally conceived. A total of 40 applications were performed. Each application of Calla 1452 was performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity
   a. Sprayed all LRUs with nozzle distance of 18 – 24 inches

- Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal with linear spray velocity of 25 inches per second
- Glare shield LRUs: Single right/left pass normal to LRU surfaces with linear spray velocity of 25 inches per second
- [redacted] MKP: Single up/down pass normal to surface with linear spray velocity of 38 inches per second
- Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal with linear spray velocity of 25 inches per second

2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 3 minutes
5. Sprayed a third coat of Calla 1452 on all LRUs per step 1, except with linear spray velocity of 38 inches per second for all LRUs
6. Waited 53 minutes (1 hour total from start of spray)
7. Repeated steps 1 – 6 until 20 applications were completed
8. Visually examined LRUs, test fixtures, robot and Calla 1452 reservoir level (top off when required)
9. Repeated steps 1 – 8 (for 40 total applications)
10. Performed function check of all LRUs
11. Disassembly of LRUs that fail function check or exhibit non-ideal behavior

Phase III.6

The setup of this testing was identical to that of Phase III.4, without the issue caused by the Kuka robot failure. A total of 80 applications were performed. Each application of Calla 1452 was performed as follows:

1. Sprayed a coat of Calla 1452 on all LRUs using the following periodicity
   b. Sprayed all LRUs with nozzle distance of 18 – 24 inches
      - Overhead LRUs: 3 alternating left/right passes moving from top to bottom each pass. Sprayed upward approximately 45° from horizontal with linear spray velocity of 38 inches per second
      - Glare shield LRUs: Single right/left pass normal to LRU surfaces with linear spray velocity of 38 inches per second
      - [redacted] MKP: Single up/down pass normal to surface with linear spray velocity of 38 inches per second
      - Aisle stand LRUs: Single right/left pass, spraying downward approximately 45° from horizontal with linear spray velocity of 38 inches per second
2. Waited 3 minutes
3. Sprayed a second coat of Calla 1452 on all LRUs per step 1
4. Waited 3 minutes
5. Sprayed a third coat of Calla 1452 on all LRUs per step 1, except with linear spray velocity of 38 inches per second for all LRUs
6. Waited 53 minutes (1 hour total from start of spray)
7. Repeated steps 1 – 6 until 20 applications were completed
8. Visually examined LRUs, test fixtures, robot and Calla 1452 reservoir level (top off when required)
9. Repeated steps 1 – 8 (for 80 total applications)
10. Performed function check of all LRUs
11. Disassembly of LRUs

Results

Phase III.1 Results

Equipment was function checked in the as-received condition; no faults were identified. The application of Calla 1452 on the [redacted] LRUs were done in a randomized set of applications in the following order: 1 application, 3 applications, 4 applications and 2 applications for the total of 10 applications. Each application consisted of two coats of Calla 1452.

All function checks performed on the [redacted] LRUs after completion of each set of applications revealed no functional issues. The disassembly performed after completion of the set of 1 and set of 3 applications revealed no indications of ingress. After the set of 4 applications, minor indications of ingress were observed on the inside surface of the light plate housing of the multifunction keypad (MKP) (Figure 4). After the set of 2 applications, indication of ingress was also observed on the MKP, on the inside surface of the light plate housing, and along the bottom edge of the housing under the light plate (Figure 5). Functional test results were recorded; no faults were identified.

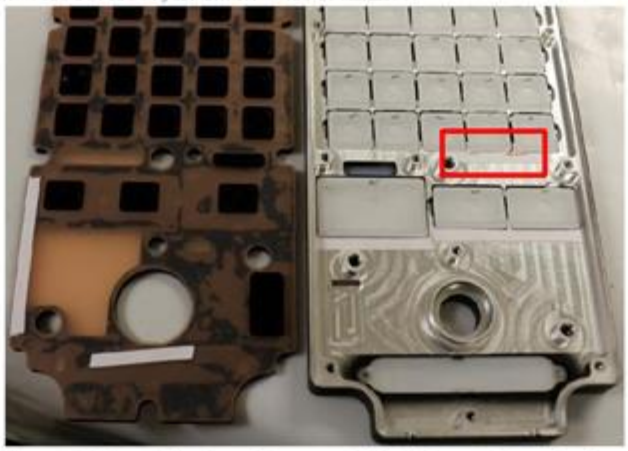

Figure 4: Minor indication of ingress on MKP after set of 4 applications

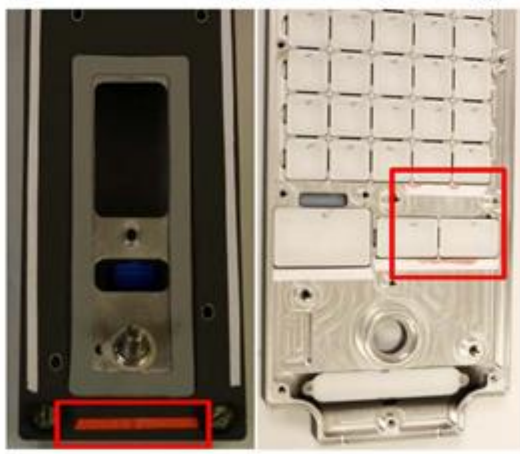

Figure 5: Indication of ingress on MKP after set of 2 applications

The application of Calla 1452 on the [redacted] LRUs were also randomized by sets of applications in the following order: 1 application, 4 applications, 3 applications and 2 applications for the total of 10 applications. Each application consisted of two coats of Calla 1452. After completion of the set of 1 application, the function check did not reveal any functional issues.
Indications of ingress were observed on the fuel control panel behind the light plate (Figure 6).

Figure 6: Indications of ingress observed on fuel control panel after set of 1 application

After the set of 4 applications, no functional issues were found. Indications of ingress were observed on the outside perimeter of the audio control panel (ACP), and around the edges under the light plate (Figure 7).

Figure 7: Indications of ingress observed on ACP after set of 4 applications

After the set of 3 applications, the function check revealed that the ACP "PA" button needed two press attempts to deactivate the light. All other LRUs had no functional issues. Indications of ingress were observed on the fuel control panel behind the light plate and around the edges of the ACP under the light plate (Figure 8).

Figure 8: Indications of ingress after set of 3 applications on fuel control panel (left) and ACP (right)

After the set of 2 applications, no functional issues were found. Indications of ingress were observed on the pressure selector panel and around the edges of the ACP under the light plate (Figure 9).

Figure 9: Indications of ingress after set of 2 applications on pressure selector panel (top) and ACP (bottom)

Phase III.2 Results

After 20 applications of Calla 1452 with the Kuka robot, or 30 total applications, disassembly of all LRUs was performed immediately after the last application. The [redacted] display control panel (DCP) and the differential pressure indicator were the only LRUs to not exhibit any indications of ingress. The results of disassembly for all LRUs are shown in Table 2. "Minor ingress" in this case is defined as small indications of ingress observed around the outside perimeter of the LRU and/or under light plates, but not near any critical components such as a circuit board. Images of these LRUs will not be shown in this report. An example of an LRU that was considered to have "minor ingress" is the tuning and control panel (TCP) shown in Figure 10. All other results are shown in Figure 11 through Figure 14. A function check was not performed in this phase of testing due to minimal indications of ingress observed.

Table 2: Results of Disassembly of LRUs after Phase III.2 Testing

#	Model	Description	Result
1	[redacted]	Audio Control Panel (ACP)	Minor ingress
2		P5-13 Electric Meters, Battery and Galley Power Panel	Figure 11
3		P5-6 Cabin Pressure Selector Panel	Minor ingress
4		PR-2 Fuel Control Panel	Figure 12
5		Cabin Altimeter - Differential Pressure Indicator	No indications of ingress
6		Mode Control Panel (MCP)	Figure 13
7	[redacted]	Alerting and Transponder Control	Minor ingress
8		Multifunction Keypad (MKP)	Figure 14
9		Audio Control Panel (ACP)	Minor ingress
10		Tuning and Control Panel (TCP)	Minor ingress
11		Display Control Panel (DCP)	No indications of ingress

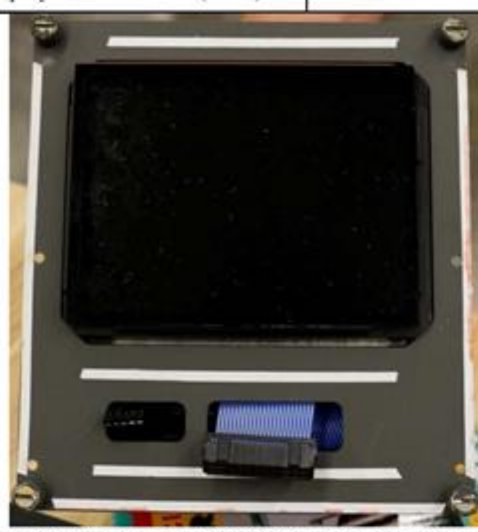

Figure 10: Indications of ingress on TCP considered to be "minor ingress"

Figure 11: Calla 1452 remaining on knobs of P5-13 panel after 10 -12 minute dwell time

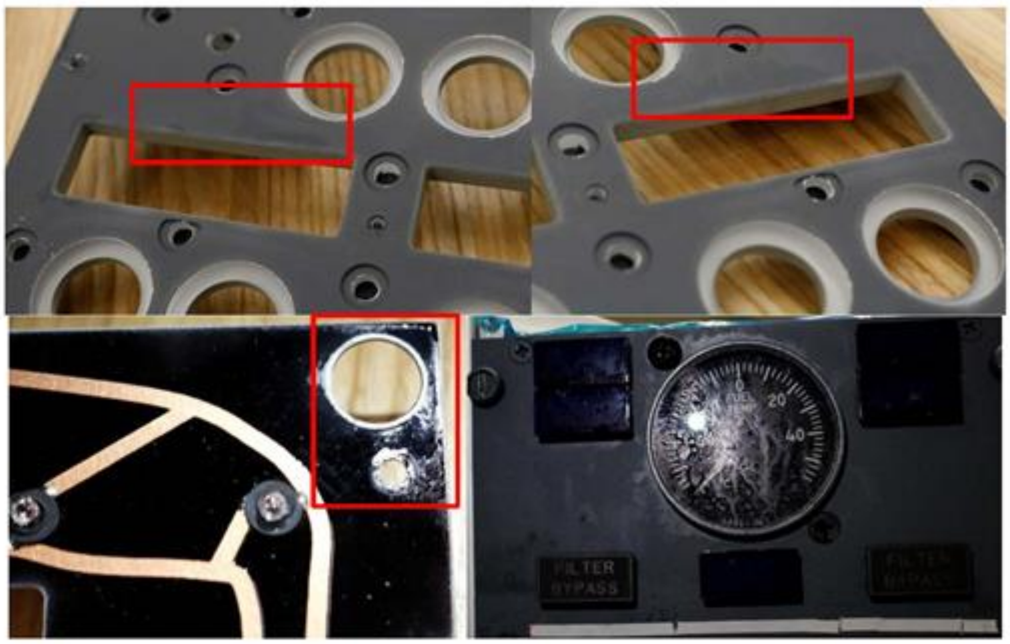

Figure 12: Moisture and residue observed on fuel control panel components

Figure 13: Calla 1452 remaining along bottom edge of MCP light plate after 10 _ 12 minute dwell time

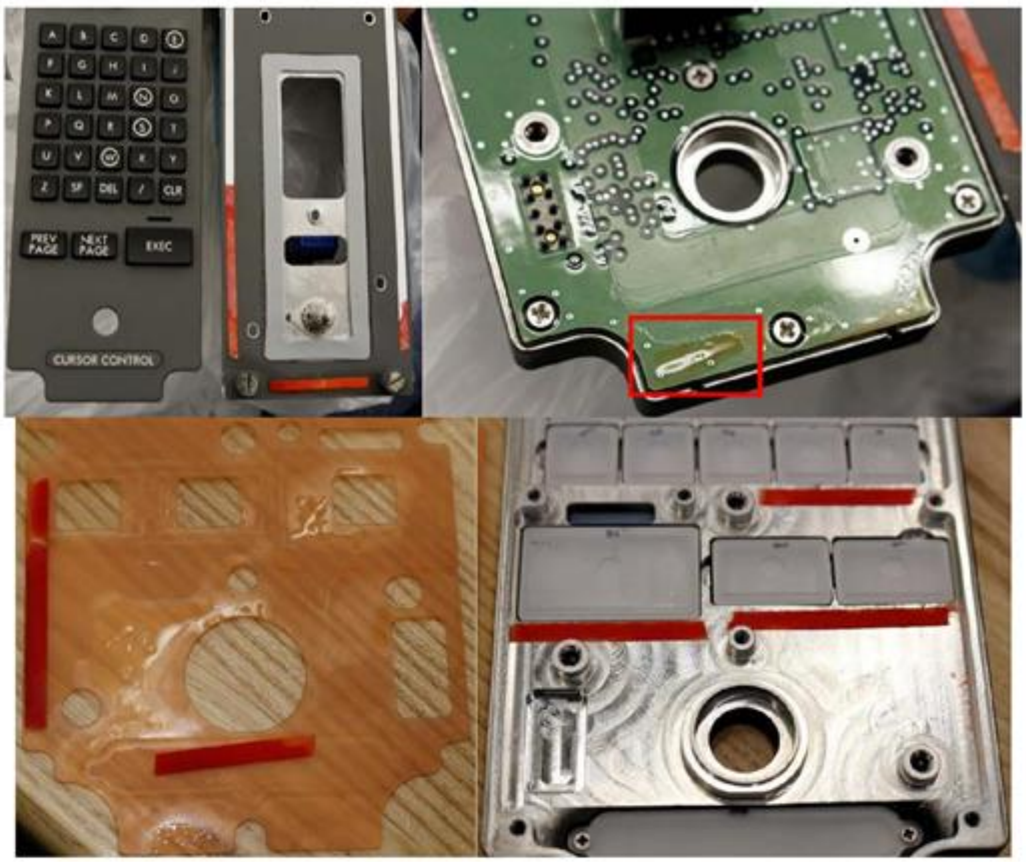

Figure 14: Indications of ingress and remaining liquid observed on MKP assembly

Phase III.3 Results

After another 20 applications of Calla 1452 with the Kuka robot, or a total of 50 applications, disassembly of all LRUs was performed immediately after the last application. The results are as shown in Table 3 and Figure 16 through Figure 20. A function check was performed showing no functional issues with any of the LRUs, except for the tuning and control panel (TCP), despite exhibiting minor indications of ingress around the perimeter under the light plate assembly (Figure 15). The TCP had buttons that required several pushes to function. Some of the buttons' functionality improved with increased usage, while some other buttons continued to require several pushes to function. An additional disassembly after function check revealed that the light plate had been reassembled incorrectly with the light diffuser sheet installed between the rubber pad and the printed wiring board. As a result, the light diffuser sheet caused gapping between the rubber pad and the printed wiring board contacts. This also resulted in the light diffuser sheet being dimpled by the light emitting diodes during attempts to operate the buttons (Figure 15). When the TCP was reassembled with the light diffuser sheet in the correct location, the buttons functioned properly.

Table 3: Results of Disassembly of LRUs after Phase III.3 Testing

#	Model	Description	Result
1	[redacted]	Audio Control Panel (ACP)	Minor ingress
2		P5-13 Electric Meters, Battery and Galley Power Panel	Figure 16
3		P5-6 Cabin Pressure Selector Panel	No indications of ingress
4		PR-2 Fuel Control Panel	Figure 17
5		Cabin Altimeter - Differential Pressure Indicator	No indications of ingress
6		Mode Control Panel (MCP)	Figure 18
7	[redacted]	Alerting and Transponder Control	No indications of ingress
8		Multifunction Keypad (MKP)	Figure 19
9		Audio Control Panel (ACP)	Minor ingress
10		Tuning and Control Panel (TCP)	Minor ingress
11		Display Control Panel (DCP)	Figure 20

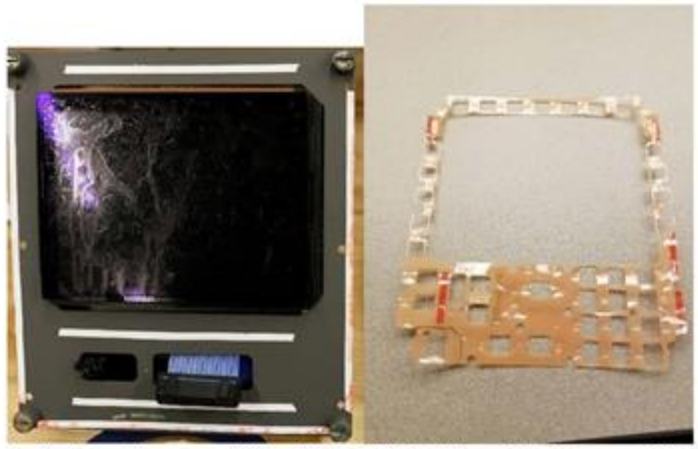

Figure 15: Minor indications of ingress on TCP and dimpled light diffuser sheet (tape was white on reverse side)

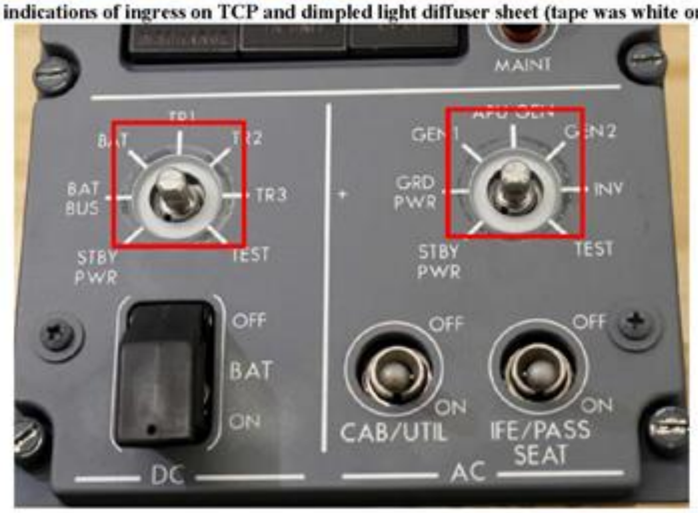

Figure 16: Calla 1452 residue build up behind knobs of P5-13 panel

Figure 17: Calla 1452 residue on white switches and moisture on back side of light plate of fuel control panel

Figure 18: Calla 1452 residue and pooling along bottom edge of MCP light plate

Figure 19: Indications of ingress in MKP assembly

Figure 20: Indications of Calla 1452 dripping and residue on [redacted] DCP

Phase III.4 Results

After completion of the 40 applications of Calla 1452 with the Kuka robot in Phase III.4, or a total of 90 applications, a function check was performed first. No functional issues were found on any of the LRUs except for the alerting and transponder control despite only exhibiting minor indications of ingress around the perimeter of the LRU under the light plate assembly (Figure 21). The lights on the transponder functioned, but the transponder itself initially did function and an ICAS message was generated. Approximately 20 minutes into the function check, the transponder ICAS message cleared and it functioned as normal. The TCP that had functional issues after Phase III.3 performed as normal. The disassembly of all LRUs was performed at least 24 hours after the last application. The results of disassembly of all LRUs are as shown in Table 4 and Figure 22 through Figure 30.

Table 4: Results of disassembly of LRUs after Phase III.4 Testing

#	Model	Description	Result
1	[redacted]	Audio Control Panel (ACP)	Figure 22
2		P5-13 Electric Meters, Battery and Galley Power Panel	Figure 23
3		P5-6 Cabin Pressure Selector Panel	Figure 24
4		PR-2 Fuel Control Panel	Figure 25
5		Cabin Altimeter - Differential Pressure Indicator	Minor ingress
6		Mode Control Panel (MCP)	Figure 26
7	[redacted]	Alerting and Transponder Control	Minor ingress
8		Multifunction Keypad (MKP)	Figure 27
9		Audio Control Panel (ACP)	Figure 28
10		Tuning and Control Panel (TCP)	Figure 29
11		Display Control Panel (DCP)	Figure 30

Figure 21: Minor indications of ingress on alerting and transponder control

Figure 22: Indications of ingress in [redacted] ACP under the light plate and residue between button cutouts

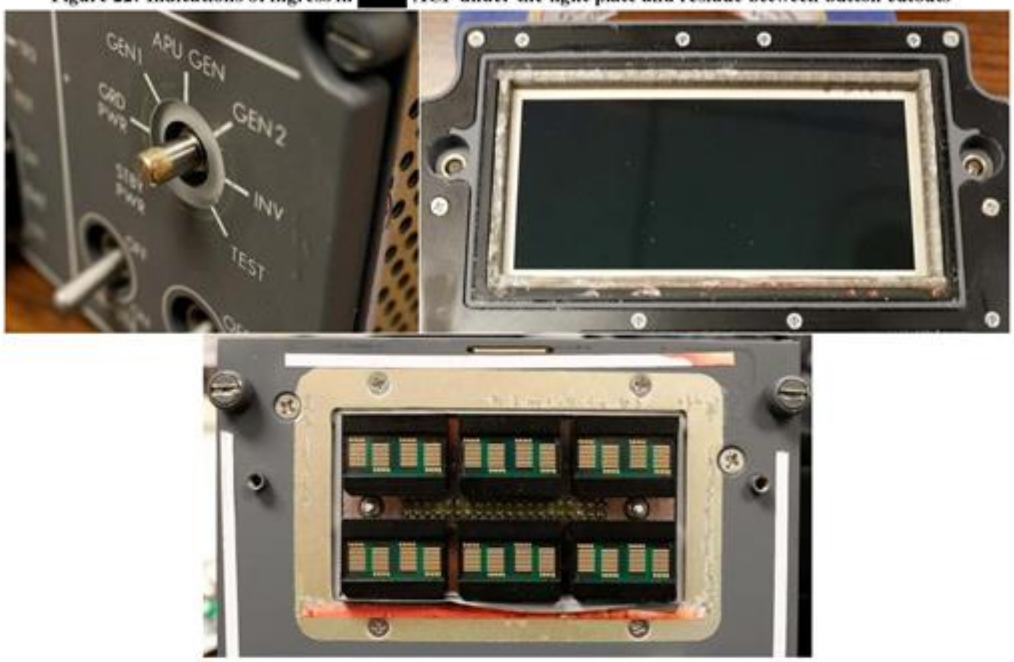

Figure 23: Calla 1452 residue and corrosion at knob locations, and residue behind display of P5-13 panel

Figure 24: Indications of ingress and residue build up on cabin pressure selector panel

Figure 25: Indications of ingress on fuel control panel and degradation of conformal coating on circuit board

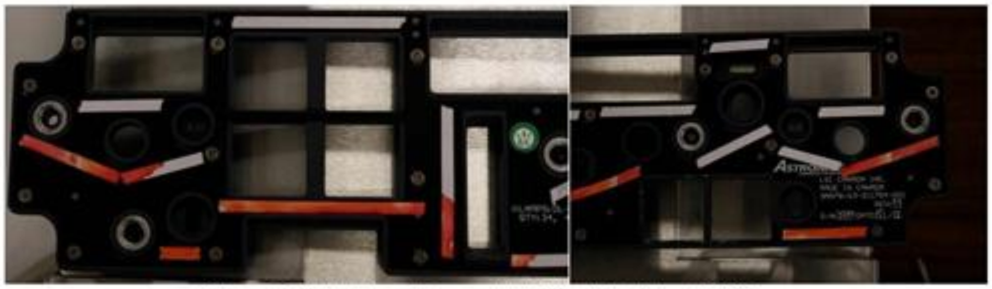

Figure 26: Indications of ingress behind the light plate of MCP

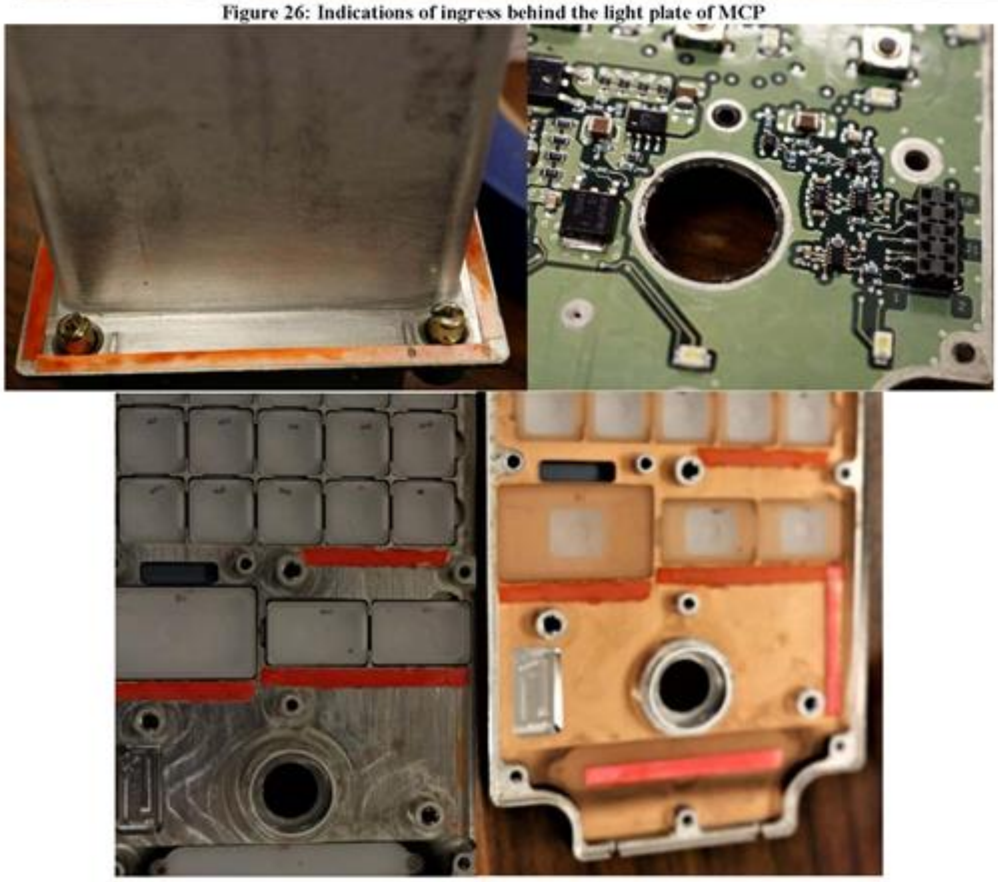

Figure 27: Indications of ingress and corrosion in MKP assembly

Figure 28: Indications of ingress in [redacted] ACP

Figure 29: Indications of ingress in [redacted] TCP and corrosion development around screw holes

Figure 30: Indications of ingress on [redacted] DCP

Phase III.5 Results

After completion of the 40 applications of Calla 1452 with the Kuka robot in Phase III.5, or a total of 130 applications, a function check was performed. Since the spray exposure regimen of Phase III.5 was intended to perform the original Phase III.4 test, and due to the bottle discharge during Phase III.4 exposure was expected to be a more severe exposure, full disassembly and inspection were only performed on LRUs which exhibited functional issues or an off-nominal experience for the functional test operator. Functional testing identified that the P5-6 Cabin Pressure Selector Panel outflow valve switch did not operate in the "CLOSE" position. Additionally, the [redacted] TCP buttons were reported to feel sticky. As a result, these two LRUs were disassembled as far as possible without destruction, at least 24 hours after the last application of Calla 1452. The results of disassembly of all LRUs are as shown in Table 5 and Figures 31 through 44. It should be noted that the time between the last e-spray and any full disassembly exceeded eight days due to an issue within [redacted] Shipping.

Table 5: Results of disassembly of LRUs after Phase III.5 Testing

#	Model	Description	Result
1		Audio Control Panel (ACP)	Figure 31
2		P5-13 Electric Meters, Battery and Galley Power Panel	Figure 32
3	[redacted]	P5-6 Cabin Pressure Selector Panel	Figures 33 to 35
4		PR-2 Fuel Control Panel	Figure 2536
5		Cabin Altimeter - Differential Pressure Indicator	Figure 37
6		Mode Control Panel (MCP)	Figure 38
7		Alerting and Transponder Control	Figure 39
8		Multifunction Keypad (MKP)	Figure 40
9	[redacted]	Audio Control Panel (ACP)	Figure 28
10		Tuning and Control Panel (TCP)	Figure 29 and 43
11		Display Control Panel (DCP)	Figure 44

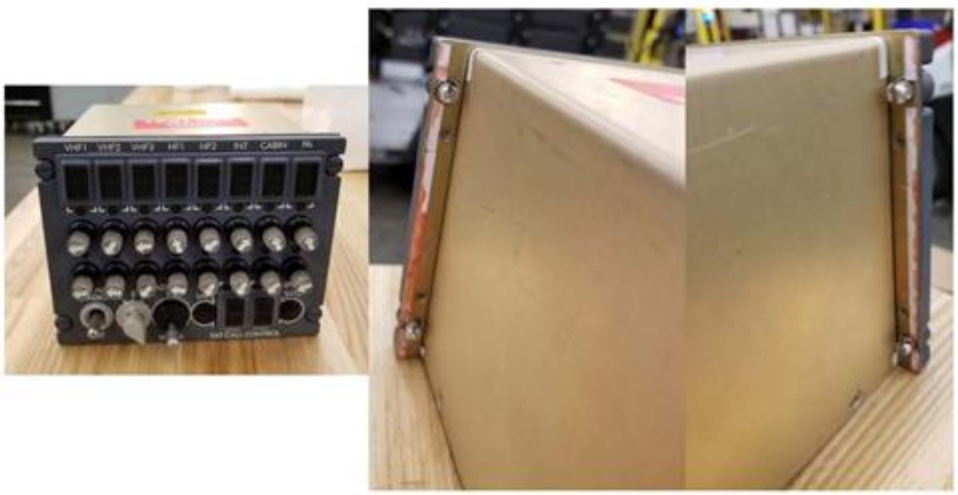

Figure 31. Left: Photo of the [redacted] ACP after 130 applications of Calla 1452. Center and Right: Photos of the same LRU, reverse side, indicating fluid ingress between the underside of the lip of the housing front plate and the mounting provisions, as evidenced by red fluid intrusion tape.

Figure 32. Left: Photo of [redacted] P5-13 after 130 applications of Calla 1452. Residue was visible on the display screen. Center and Right: Photos of the same LRU, reverse side, indicating minor fluid ingress between the underside of the lip of the housing front plate and the mounting provisions, as evidenced by faint red fluid intrusion tape (red arrows).

Figure 33. Left: Photo of [redacted] P5-6 Cabin Pressure Selector Panel after 130 applications of Calla 1452. Residue was visible on the display screens. Top Center and Right: Photos of the obverse side of the display plate after removal, showing residue on the display screens and wet residue or fluid under the knobs (white arrows). Bottom Center: Photo of the housing front plate with display plate removed. Indicator tape was red in many locations, indicating fluid ingress between the display plate and housing front plate. Evidence of moisture ingress behind the front plate was not observed visually, even with the aid of a flashlight. Due to the design of the housing, further non-destructive disassembly was not possible.

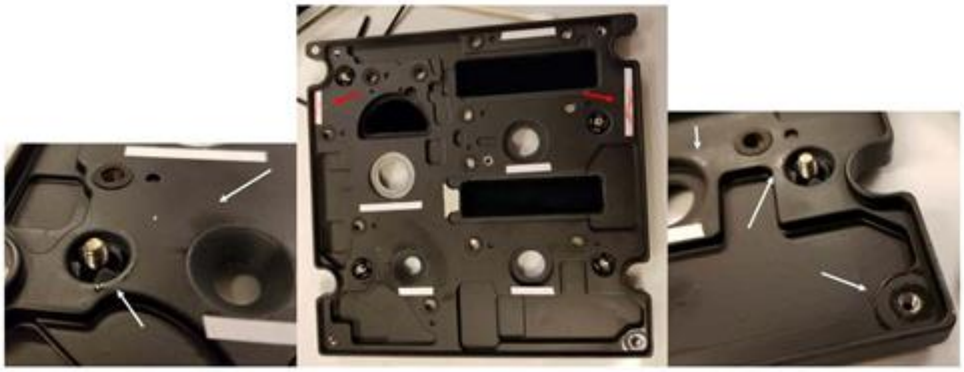

Figure 34. Photos of the underside of the [redacted] P5-6 Cabin Pressure Selector Panel display plate after 130 applications of Calla 1452. Wet residue (white arrows) was visible on some flat surfaces, around knob and switch holes and around fastener holes. Fluid ingress along the sides of the display plate was evidenced by red fluid detection tap (red arrows).

Figure 35. Photos of the [redacted] P5-6 Cabin Pressure Selector Panel display plate printed wiring board after 130 applications of Calla 1452. Residue (white arrow) was visible around the selector knob cutout. An evaporate trail (red arrow) was visible on the conformal coating near the semicircular LED display. These features were not thought to be direct contributors of the observed inoperative switch.

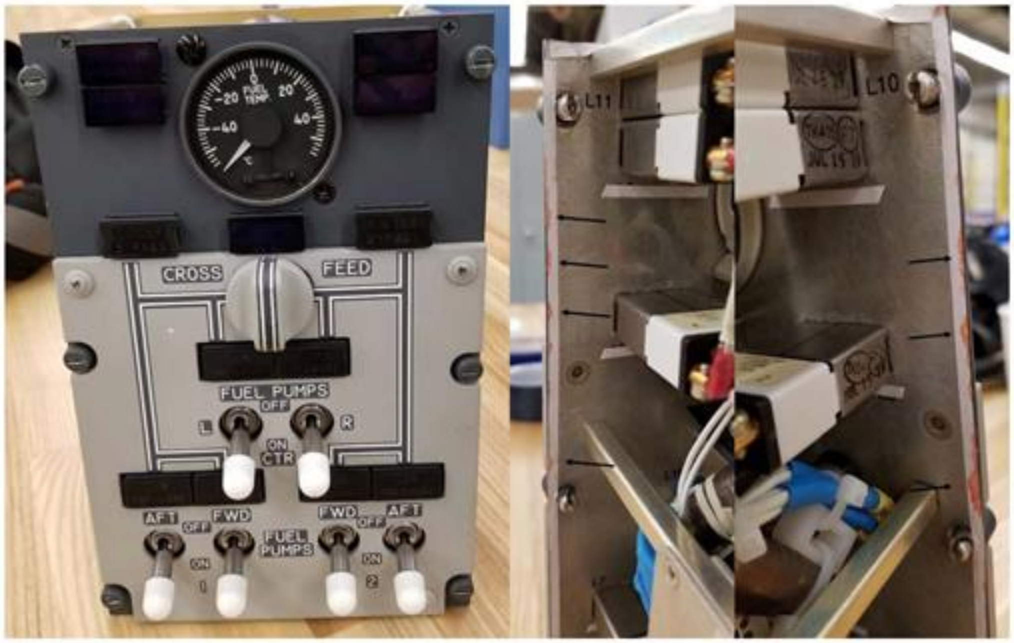

Figure 36. Left: Photo of [redacted] PR-2 Fuel Control Panel after 130 applications of Calla 1452. Center and Right: Photos of the same LRU, reverse side, indicating minor fluid ingress between the underside of the lip of the housing front plate and the mounting provisions, as evidenced by faint red fluid intrusion tape (red arrows).

Figure 37. Left: Photo of the [redacted] Cabin Altimeter - Differential Pressure Indicator after 130 applications of Calla 1452. Center and Right: Photos of the same LRU, reverse side, indicating fluid ingress between the undersides of the front plate and mounting provisions, as evidenced by red fluid intrusion tape.

Figure 38. Top: Photo of [redacted] Mode Control Panel after 130 applications of Calla 1452. Bottom Row: Photos of the same LRU from the top and bottom sides, indicating minor fluid ingress between the underside of the housing and the mounting provisions, as evidenced by red fluid intrusion tape.

Figure 39. Left: Photo of [redacted] Alerting and Transponder Control after 130 applications of Calla 1452. Center and Right: Photos of the same LRU from the reverse, indicating fluid ingress between the underside of the housing and the mounting provisions, as evidenced by red fluid intrusion tape.

Figure 40. Left: Photo of [redacted] Multifunction Keypad after 130 applications of Calla 1452. Center and Right: Photos of the same LRU from the reverse, indicating fluid ingress along the underside of the housing, as evidenced by red fluid intrusion tape.

Figure 41. Left: Photo of [redacted] ACP after 130 applications of Calla 1452. Center and Right: Photos of the same LRU from the reverse, indicating fluid ingress between the undersides of the housing front plate and mounting provisions, as evidenced by red fluid intrusion tape.

Figure 42. Left: Photo of [redacted] TCP after 130 applications of Calla 1452. Center and Right: Photos of the same LRU from the reverse, indicating fluid ingress between the undersides of the housing front plate and mounting provisions, as evidenced by red fluid intrusion tape.

Figure 43. Left: Photo of [redacted] TCP after 130 applications of Calla 1452 with light plate removed. Red fluid intrusion tap indicated the extent of fluid ingress between the light plate and the front plate of the housing. Top Right: Photo of the light plate reverse side, showing wet residue along the joint common to the light plate housing and along the cut for the display screen. Bottom Right: Photo of the light diffuser showing dimple marks (black arrows) due to previous misassembly (see Phase III.3 Results), and a likely contributor to button sticking.

Figure 44. Top: Photo of [redacted] DCP after 130 applications of Calla 1452. Bottom: Photo of the same LRU from bottom side, indicating fluid ingress between the housing and mounting provisions, as evidenced by red fluid intrusion tape.

Phase III.6 Results

After completion of the 80 applications of Calla 1452 with the Kuka robot in Phase III.6, or a total of 210 applications, a function check was performed. The [redacted] ACP exhibited multiple volume adjustor indicator lights when all should have been off. The previously observed issue with [redacted] P5-6 Cabin Pressure Selector Panel remained (see Phase III.4 Results for details). The [redacted] ACP indicator lights failed to come on. The disassembly of all LRUs was performed at least 24 hours after the last application. Evidence of corrosion was observed on both the [redacted] ACP and [redacted] ACP printed wiring boards or components (see Figures 47 and 61). The results of disassembly of all LRUs are as shown in Figures 45 through 65.

Table 6: Results of disassembly of LRUs after Phase III.5 Testing

#	Model	Description	Result
1		Audio Control Panel (ACP)	Figures 45 to 47
2		P5-13 Electric Meters, Battery and Galley Power Panel	Figure 23
3	[redacted]	P5-6 Cabin Pressure Selector Panel	Figure 24
4		PR-2 Fuel Control Panel	Figure 25
5		Cabin Altimeter - Differential Pressure Indicator	Figure 55
6		Mode Control Panel (MCP)	Figure 26
7		Alerting and Transponder Control	Figure 58
8		Multifunction Keypad (MKP)	Figure 59
9	[redacted]	Audio Control Panel (ACP)	Figure 28
10		Tuning and Control Panel (TCP)	Figure 64
11		Display Control Panel (DCP)	Figure 65

Figure 45. Multiple channel indicator lights were active simultaneously during Phase III.6 function check of [redacted] ACP

Figure 46. Photos of [redacted] ACP after 210 applications of Calla 1452. Photos indicate fluid ingress between the housing and mounting provisions, as evidenced by red fluid intrusion tape (photos taken after removal of light plate mounting screws).

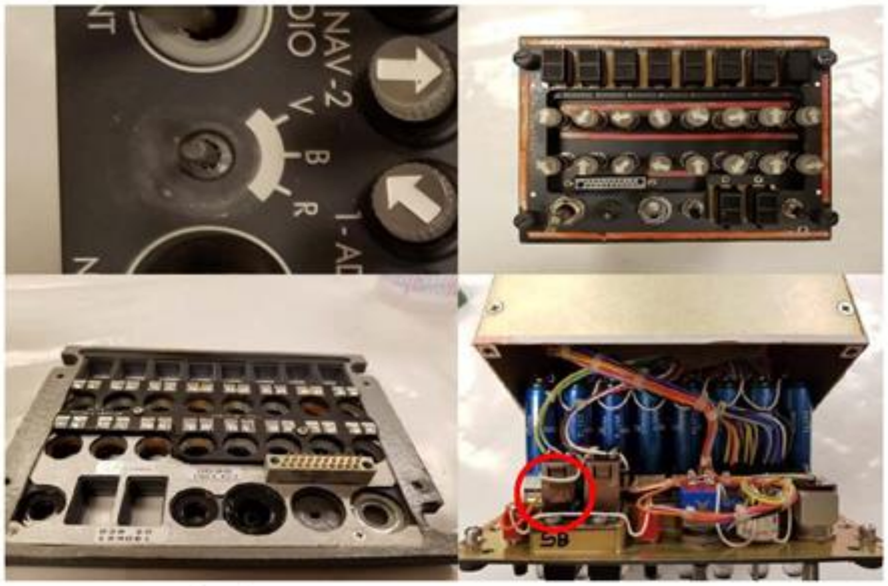

Figure 47. Photographs of [redacted] ACP during disassembly showing evidence of fluid intrusion, red indicator tape or whitish residue and corrosion (circled in red lower right)

Figure 48. Photos showing external condition of [redacted] P5-13 panel after 210th application of Calla 1452. The indicator tape has turned red (black arrows) along an edge of the back side of the housing lip, indicating the presence of relatively small quantities of fluid ingress between the panel housing and the mounting provisions.

Figure 49. Photos showing condition of [redacted] P5-13 panel during disassembly after 210th application of Calla 1452. Left: Fluid residue was present between both knobs and the light plate. Upper Right: Fluid (white arrow) was present on the reverse side of the light plate. Lower Right: Fluid (red arrows) was present on the reverse side of the light plate, between the light plate and printed wiring board (not shown).

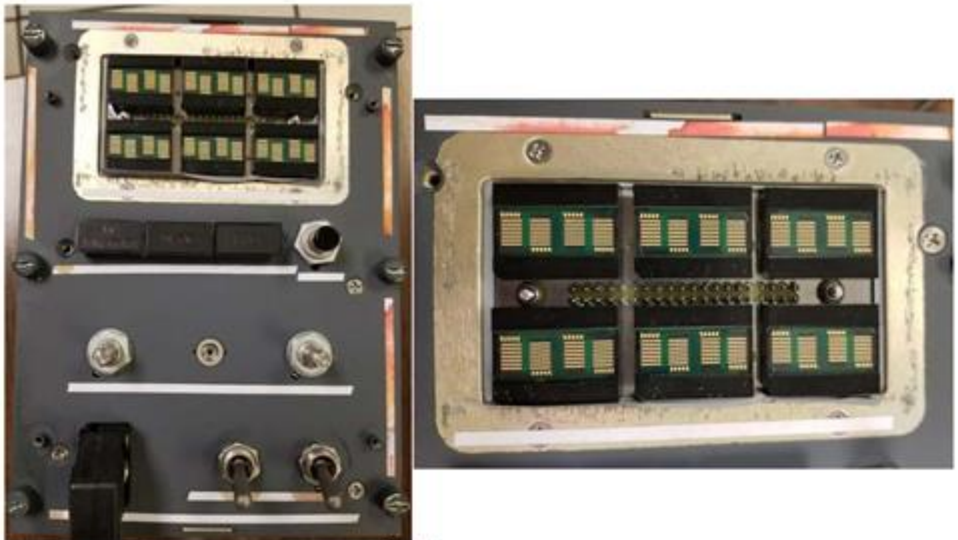

Figure 50. Additional photos showing condition of [redacted] P5-13 panel during disassembly after 210th application of Calla 1452. Left: Photo of housing face plate with red indicator tape, indicating fluid ingress between light plate and face plate. Fluid residue was present on the face plate coincident with the cut out holes for both switches. Right: Photo of housing face plate around the LED (compare with Figure 23).

Figure 51. Left: Photo showing external condition of [redacted] P5-6 Cabin Pressure Selector Panel after 210th application of
Calla 1452. None of the indicator tape applied externally had turned red (not shown). Upper Center: Photo of same LRU with knobs removed. Rings of fluid residue were present under all knobs. Lower Center: Photo of manual control switch exhibiting a white powdery substance, consistent with corrosion product. Right: Photo of loosened display plate attachment screws, showing a white powdery substance coincident with a shim or washer under the fastener head.

Figure 52. Additional photos of [redacted] P5-6 Cabin Pressure Selector Panel during disassembly. Upper Left: Photo of same LRU with display plate removed, revealing significant amounts of fluid were present between the housing front plate and the display plate, as evidenced by red indicating tape. Bottom Left: Close-up of manual control switch with white powder, likely corrosion product. Upper Right: Photo of the inside surface of the display plate with printed wiring board removed. Fluid was present around most corner inserts, and residue from previous exposure cycles remained. Bottom Center Photos: Close-ups of the red indicator tape and fluid residue around insert in corner. Lower Right: Photo of the display plate printed wiring board with fluid around the fastener hole.

Figure 53. Photos showing external condition of [redacted] Fuel Control Panel after 210th application of Calla 1452. The indicator tape was red along several edges of the back side of the housing front plate, indicating the presence of relatively large quantities of fluid ingress between the panel front plate and the mounting provisions.

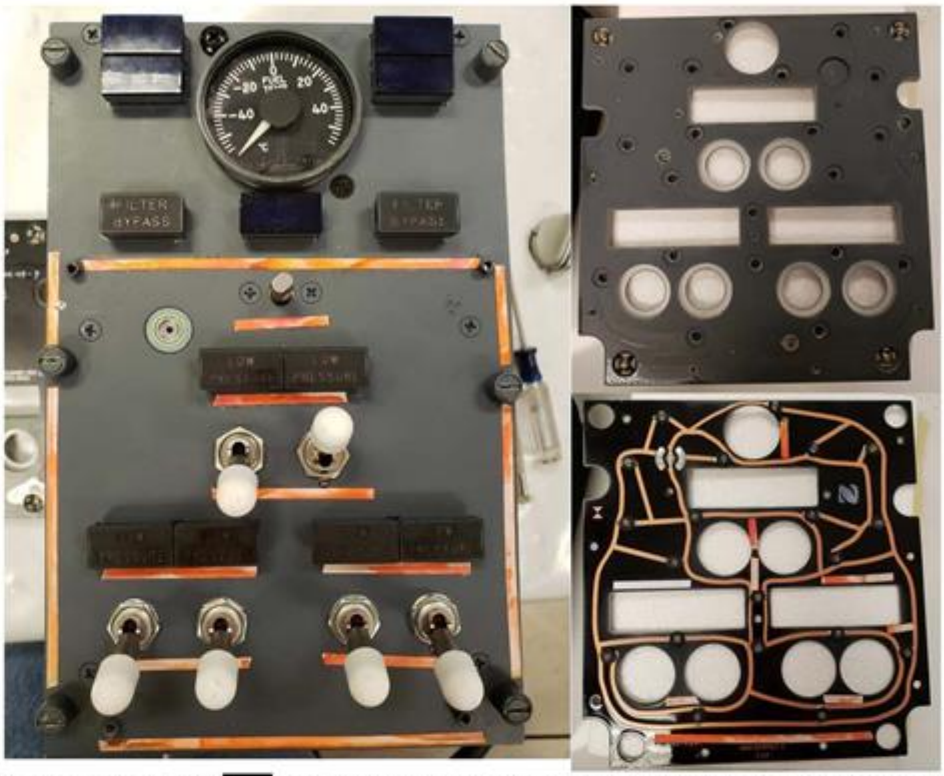

Figure 54. Photos showing [redacted] Fuel Control Panel during disassembly after 210th application of Calla 1452. Left: Photo of same LRU with light plate removed. The majority of indicator tape was red, indicating the presence of relatively large quantities of fluid ingress between the panel front plate and the light plate. Right: Photos of the disassembled light plate, showing fluid residue on the light plate along the edges and red indicator tape on the printed wiring board, suggesting relatively large quantities of fluid ingress.

Figure 55. Photos showing condition of [redacted] Cabin Altimeter and Differential Pressure Indicator panel after 210th application of Calla 1452. The indicator tape has turned red along several edges of the reverse side of the front plate, indicating the presence of relatively large quantities of fluid ingress between the front plate and the panel mounting provisions. The bottom photos show a white powdery substance emanating from under a fastener screw and along the joint of the altimeter canister faceplate.

Figure 56. Photos showing external condition of [redacted] MCP after 210th application of Calla 1452. The indicator tape was red along some portions of the lower surface of the housing (e.g., black arrow), indicating the presence of relatively small quantities of fluid ingress.

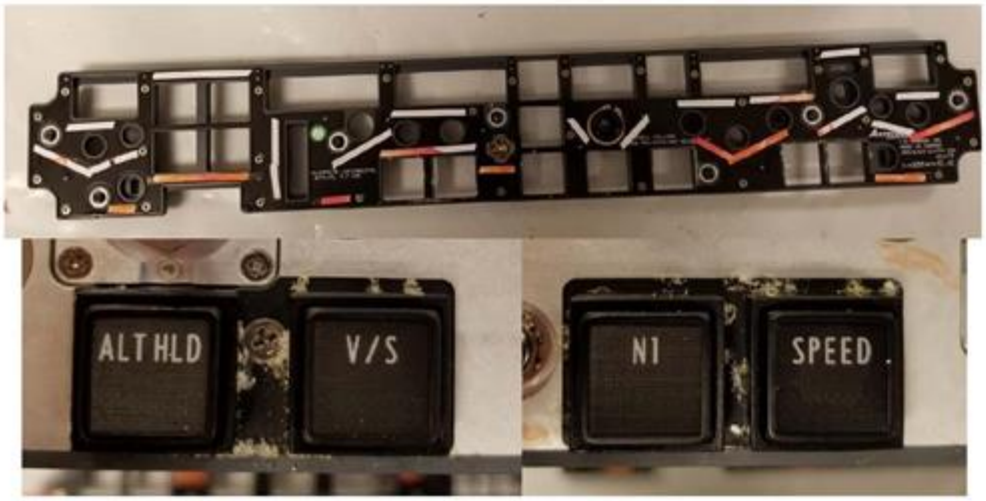

Figure 57. Top: Photo of the reverse side of [redacted] MCP light plate showing red fluid indicator tape, evidence of fluid intrusion. Lower Left and Right: Photos of the front of the MCP housing with light plate removed, showing a whitish powdery substance, likely corrosion product.

Figure 58. The [redacted] Alerting and Transponder Control had significant fluid ingress behind the light plate. Corrosion between the selector knob set screw and shaft was sufficient to preclude hand disassembly. Residue was present between the knob and face plate.

Figure 59. Photos showing condition of [redacted] MKP after 210th application of Calla 1452. Top Left and Top Center: Exterior condition of the MKP after spray; red tape on the reverse side of the housing lip indicated fluid ingress between the housing and mounting provisions of the test rig. Top Right: Forward face of the housing with red tape along the lower side edges indicated fluid ingress between the housing and light plate. Bottom Left: Residue (black arrows) was present along the inside corner of the reverse side of the light plate front plate, indicative of repetitive fluid intrusion and evaporation. Bottom Center: Residue was present along portions (white circle) of the rubber pad and suggests fluid contact with the mating printed wiring board surface. Bottom Right: White powder (red arrows), likely corrosion product, was present along the edge of the cutout for the dial. Also, faint whitish residue traces were present on much of the rubber pad surface.

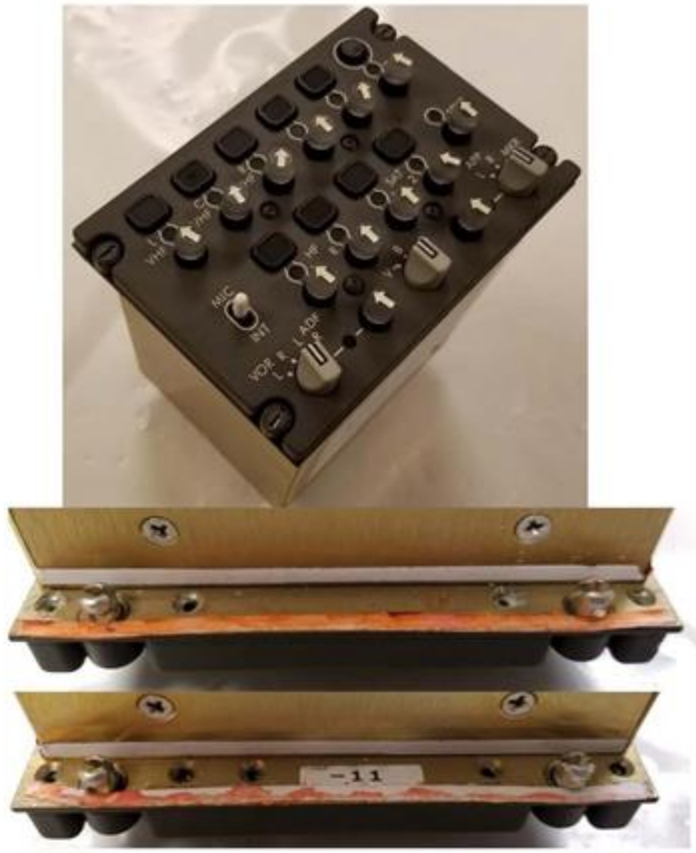

Figure 60. Photos showing condition of [redacted] ACP after 210th application of Calla 1452. Top: Exterior condition of the ACP after spray. Center and Bottom: Red tape on the reverse side of the housing lip indicated fluid ingress between the housing and mounting provisions of the test rig. A white powdery substance, likely corrosion product, was present at several of the fastener holes.

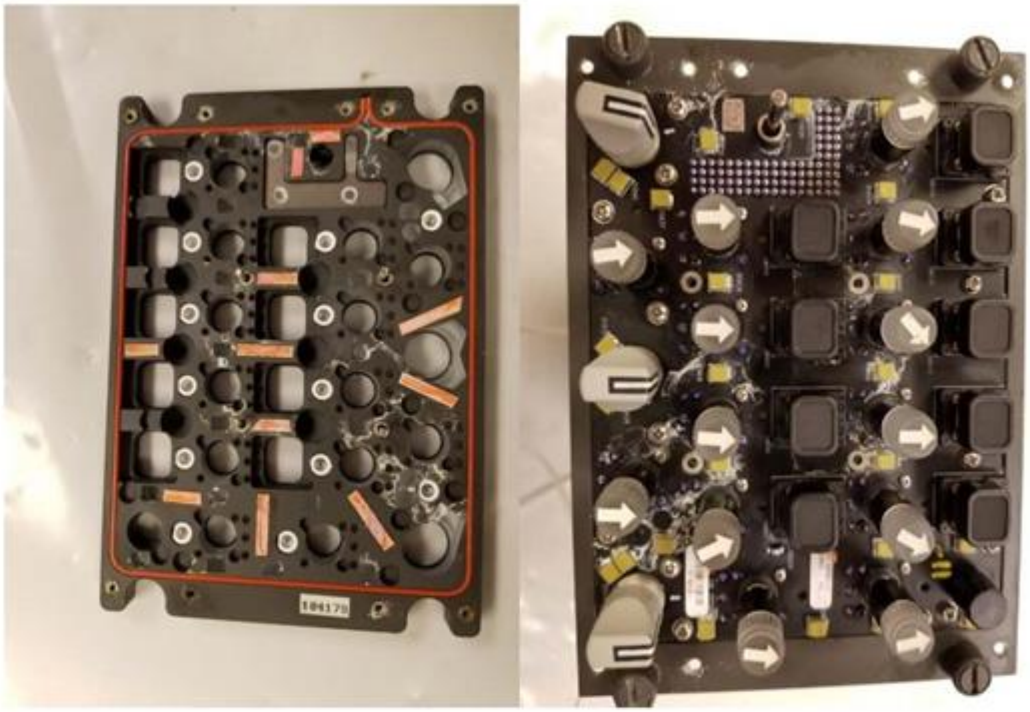

Figure 61. Photos of [redacted] ACP printed wiring board and light plate exhibiting evidence of fluid intrusion and corrosion between components, evidenced by white powder between components and associated surfaces.

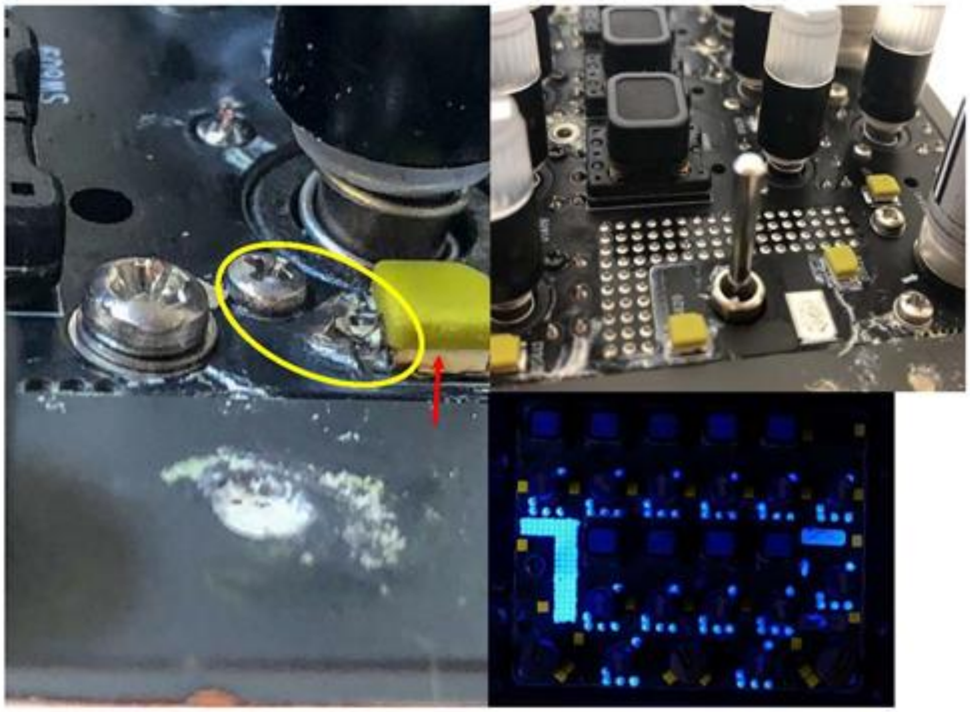

Figure 62. Examination of [redacted] ACP printed wiring board corrosion identified a shorting path associated with component DS613 (path circled in yellow). The white portion of the component (red arrow) appears thermally damaged, as is the solder joint. Where conformal coating was present, as at the solder pin array, corrosion was not noted. No clear evidence of damage to conformal coating was observed. UV light applied to the printed wiring board fluoresced on the soldered pin joints but not elsewhere, suggesting either the absence of conformal coating elsewhere or the absence of fluorescing dye in any other conformal coating.

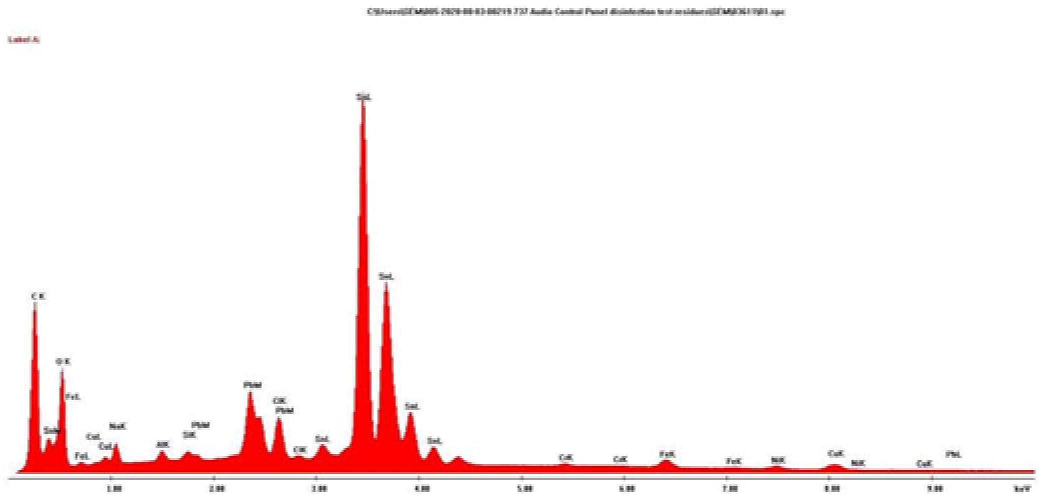

Figure 63. Energy dispersion spectroscopy results of the white corrosion product on [redacted] ACP printed wiring board, containing high amounts of tin and lead, confirming that the white corrosion product was electrical solder.

Figure 64. Photos showing condition of [redacted] TCP after 210th application of Calla 1452. Top Row: External condition of the TCP. The red tape along the underside edges of the housing indicated fluid intrusion between the housing and mounting provisions. Bottom Left: Photo showing the front plate of the housing with light plate removed. The presence of red tape along the majority of the side edges indicated fluid intrusion, but the pristine white tape (black arrows) suggested that much of the fluid never penetrated significantly interior from the joint edges. Bottom Center: Photo of the reverse side of the light plate. Fluid and residue were evident along the edges of the display cutout, suggesting repetitive fluid intrusion and evaporation. Bottom Right: Photo of the rubber pad inside of the light plate. Whitish residue was present on surface, indicating repeated fluid intrusion.

Figure 65. Photos showing condition of [redacted] DCP after 210th application of Calla 1452. Top Row: External condition of the DCP. The red tape (black arrows) along the underside edges of the housing indicated fluid intrusion between the housing and mounting provisions. Bottom: Photo showing the light plate. Residue (white arrows) was present on much of the DCP surface, especially around knobs and buttons.

Conclusions

After a cumulative 90 applications of Calla 1452, all LRUs exhibited some indications of ingress. Function checks performed showed that the amount of ingress did not significantly affect most LRUs at that point, with the exception of the [redacted] Alerting and Transponder Control, which selfresolved. Also at 90 applications, the first evidence of corrosion product was observed. After a cumulative 130 applications, the first LRU with a functional issue potentially attributable to Calla 1452 exposure was observed, the [redacted] P5-6 Cabin Pressure Selector Panel. It should be noted that a definitive correlation could not be obtained due to inability to remove or access the faulty switch from within the assembly. After a cumulative 210 applications of Calla 1452, several LRUs were no longer fully functional and many of the LRUs exhibited evidence of concentrated fluid residue in between surfaces and evidence of corrosion, notably at fasteners, knobs, and some electrical boards.

Thermal Disinfection of SARS-CoV-2 within an Airplane

Abstract

SARS-CoV-2 is a new virus in humans causing respiratory illness that is easily spreads from person-to-person.[1] Breathing, talking, singing or coughing all propel particles through the air where they can then be inhaled by a nearby person, deposited on the skin or mucosal surfaces, or finally on surfaces in the surrounding area[2]. The mode of transmission is primarily through respiratory droplets, however transmission through contact with contaminated surfaces is possible.

The use of elevated temperatures (40°C to 60°C) to disinfect airplane locations that cannot be decontaminated as effectively through more traditional means, such as the flight deck, was evaluated. [redacted] determined that portable recirculating air heaters were the most viable method for airline use. In collaboration with the University of Arizona, [redacted] conducted lab tests on SARS-CoV-2 to determine environmental conditions and times necessary to successfully inactivate 99.9% of the SARS-CoV-2 respiratory viruses.

Operators must maintain an air temperature of 40°C for approximately 305 minutes, 50°C for 200 minutes, or 55°C for 134 minutes to achieve disinfection at expected flight deck humidity conditions (<20% RH). These times do not include the time it takes to ramp up to these temperatures (ramp up time).

Background: The Effect of Temperature on SARS-CoV-2

[redacted] initially believed that the temperature range required to inactivate the SARS-CoV-2 virus was too high to be practical for use in aircraft disinfection. However, a paper released by the United States Army Medical Research Institute of Infectious Diseases (USAMRIID) came to our attention in mid-2020 which included test data showing the inactivation of the SARS-CoV-2 virus at lower temperature ranges than previously thought[6]. A vision for using thermal energy as a method for disinfecting smaller aircraft compartments, such as the flight deck, emerged.

The impact of environmental temperature on the survivability of SARS-CoV-2 on surfaces was investigated shortly after the initial discovery of the virus to determine if a seasonal effect would occur.[3] Per Chin et al.; "The virus is highly stable at 4°C, but sensitive to heat. At 4°C, there was only a 0.7 $\log_{10}$ reduction of infectious titer on day 14. With the incubation temperature increased to 70°C, the time for virus inactivation was reduced to 5 minutes."[3] As shown in Table 1, the virus can survive nearly an entire day at room (22°C) and body temperature (37°C), but became inactivated within 30 minutes at 56°C.

Table 1: Thermal Stability of SAR-CoV-2 in Virus Transport Medium[3]

Time	Virus titre (Log $TCID_{50}$/mL)									
	4°C		22°C		37°C		56°C		70°C	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
1 min	N.D.	N.D.	6.51	0.27	N.D.	N.D.	6.65	0.1	5.34	0.17
5 mins	N.D.	N.D.	6.7	0.15	N.D.	N.D.	4.62	0.44	U	-
10 mins	N.D.	N.D.	6.63	0.07	N.D.	N.D.	3.84	0.32	U	-
30 mins	6.51	0.27	6.52	0.28	6.57	0.17	U	-	U	-
1 hr	6.57	0.32	6.33	0.21	6.76	0.05	U	-	U	-
3 hrs	6.66	0.16	6.68	0.46	6.36	0.19	U	-	U	-
6 hrs	6.67	0.04	6.54	0.32	5.99	0.26	U	-	U	-
12 hrs	6.58	0.21	6.23	0.05	5.28	0.23	U	-	U	-
1 day	6.72	0.13	6.26	0.05	3.23	0.05	U	-	U	-
2 days	6.42	0.37	5.83	0.28	U	-	U	-	U	-
4 days	6.32	0.27	4.99	0.18	U	-	U	-	U	-
7 days	6.65	0.05	3.48	0.24	U	-	U	-	U	-
14 days	6.04	0.18	U	-	U	-	U	-	U	-

U: Undetectable

SD: Standard Deviation

Titer: numeric expression of viral quantity in a given fluid

Further research validated the relationship between temperature and reduction of the SARS-CoV-2.[4,5,6] Morris et al tested the half-life of viral samples at 10°C, 22°C, and 27°C and various relative humidity levels. Figure 1 shows the relationship of the virus half-life to relative humidity at various temperatures.[4] Viral half-life is defined as the time it takes to reduce the viral load by 50%. They found that the virus persists better at lower temperatures. Moreover, they found that approximately 60% relative humidity resulted in higher disinfection of the virus under thermal loading in comparison to both higher and lower relative humidity. One hypothesis proposed for the mechanistic explanation of the role humidity plays on virus reduction suggest that relative humidity affects virus inactivation by controlling evaporation and thus governs the solute concentration in a droplet containing virions. However, this has not been validated and many mechanistic principals remain elusive.[7]

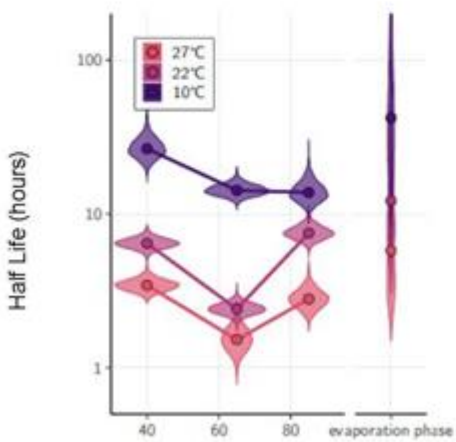

Figure 1: Relative humidity (%)[4]

Several studies were used to establish a target temperature range for airplane disinfection and to determine timeframes and environmental conditions to be evaluated through lab efficacy testing.[1,3,4,5,6] However, it should be noted that most thermal disinfection methods in the scientific community use much higher temperatures than those applicable for use on airplane. This is expanded on in the [redacted] airplane test section below.

Lab-Based Efficacy Testing

Comparative Surfaces for Common Flight Deck Materials

[redacted] collaborated with the University of Arizona to determine the stability of SARS-CoV-2 at elevated temperatures when deposited on surfaces representative of airplane interiors. [redacted] components representing three material types in the flight deck were sent for testing. An example is shown in Figure 2.

Figure 2: Example of Provided Flight Deck Hardware

Three material types including Painted Aluminum/Acrylic Back Plate, Anti-reflective Glass Indicator Lens, and Poly II Acrylic Pushbutton were selected as being good indicators of efficacy by considering a combination of factors such as availability, thermal conductivity of the materials, touch time during use, material amount, and difficulty to clean. To understand the effects of an expanded temperature and humidity range, an additional round of testing was conducted. This testing was limited to the Poly II Acrylic material (pushbutton) since it is the most touched of all the materials. Results of testing were then provided to [redacted] for analysis and application.

Targeted Viral Inactivation Rate

Prior research by the University of Arizona with non-enveloped viruses examined the percentage of viruses transferred from contaminated surfaces to a human finger.[8] Assuming a similar finger transfer rate for SAR-CoV-2, a 3 $\log_{10}$ viral inactivation (99.9%) due to heating is sufficient to consider surfaces disinfected. Work is underway to validate this assumption for SARS-CoV-2 which is an enveloped virus.

Lab Efficacy Testing Results

Figure 3 shows how each of the materials responded to the initial lab efficacy testing conducted. Time ranges of 180 minutes, 240 minutes, and 300 minutes for all materials resulted in a viral inactivation rate greater than 3 $\log_{10}$ (99.9% reduction). The results presented for all lab efficacy testing conducted show reductions of the SARS-CoV-2 virus from the contribution of thermal disinfection and natural die off of the virus.

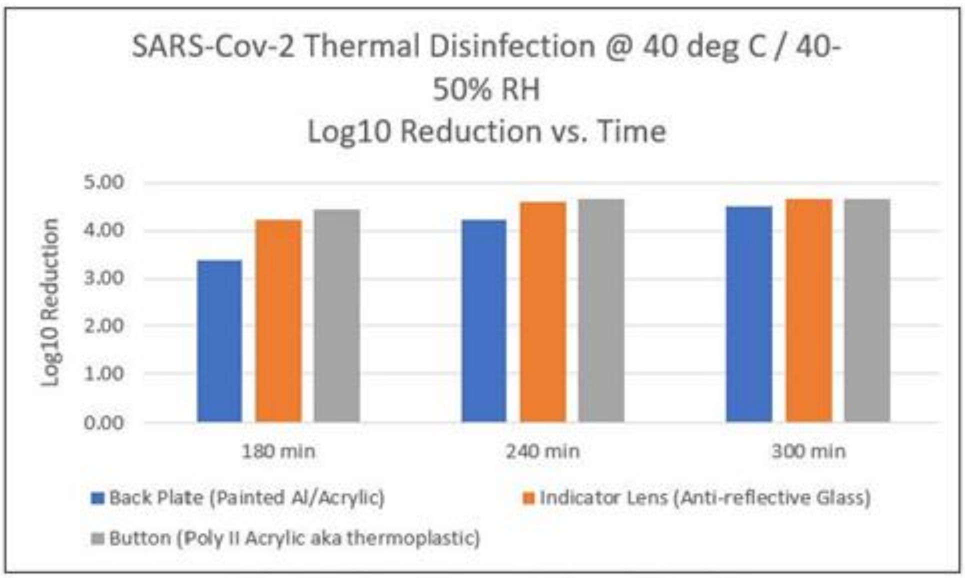

Figure 3: Surface Difference for Thermal Disinfection

The expanded temperature and humidity range testing results are shown in Table 2 for Poly II Acrylic, the common flight deck button material. The button material was selected because it was determined to be the highest touched surface. Phase 1 testing is highlighted in blue. Phase 2 testing is highlighted in green in the table. The overall goal of the Phase 2 lab testing was to determine if lower exposure times (30-120 minutes) at higher temperatures (50-55 °C), while maintaining the ambient relative humidity (40-50%) and expected airplane cabin relative humidity (<20%), played any appreciable role in an increase in viral inactivation. Overall, Phase 2 testing provided a wider range of reduction levels, as expected, and highlighted the role relative humidity plays. Lower relative humidity levels resulted in a 1-2 $\log_{10}$ reduction in viral inactivation differences for identical time and temperatures. No time frame tested at <20% RH resulted in the targeted 3 $\log_{10}$ viral inactivation rate of 99.9%. Lastly, where $\log_{10}$ reductions are reported to be greater than 4.5, the virus was not detected.

Table 2: All Testing Conducted (Blue: Phase 1, Green: Phase 2)

	Average $\log_{10}$ Reduction					
Time (min) ----->	30	60	120	180	240	300
40°C / 40-50% RH				4.44	4.67	4.67
50°C / 40-50% RH	3.00	3.50	3.56	4.61	4.61	4.61
50°C / < 20% RH	1.00	1.44	2.06			
55°C / < 20% RH	1.78	2.11	2.83			

Thermal Disinfection Analysis

In Figure 4, testing was isolated for Poly II Acrylic, the common flight deck button material. The trend lines of the data below show a strong $\log_{10}$ linear relationship between reduction and time until the reductions approach the limit of viral detection (observed as a plateau). The 40°C / 40-50% RH plot was estimated using a log-linear approximation offset from the 50°C / 40-50% RH plot and through the observed data near the limits of detection. The 50°C / <20% RH and 55°C / <20%RH plots were estimated using a log-linear approximation through the observed points. The 40°C / <20% RH plot was derived using a rough log-linear approximation and y-intercept offset to the 40°C / 40-50% plot. These plots, derived from observed data and analysis, yield approximate time intervals to reach 3 log10 (99.9%) reductions.

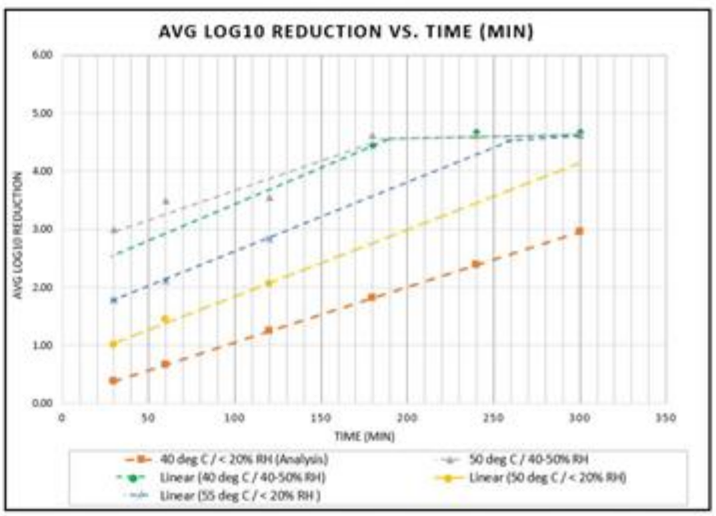

Figure 4: Relationship of RH and Temperature on Disinfection

Tables 3 and 4 summarizes the results of the lab efficacy testing performed. The time required to achieve a 99.9% reduction in the viral titer of SARS-CoV-2 (3 $\log_{10}$ inactivation) for specific temperatures and relative humidity was determined for the down selected button material.

Table 3: Predicted Time to Disinfect at 40-50% RH

Steady State Temperature at 40-50%RH	**Efficacy Achieved**	**Approximate Time Required**
40°C (104°F)	99.9%	70 minutes (1.167 hours) **predicted from data*
50°C (122°F)	99.9%	30 minutes (0.5 hours)

Table 4: Predicted Time to Disinfect at <20% RH

Steady State Temperature at <20 %RH	**Efficacy Achieved**	**Approximate Time Required**
40°C (104°F)	99.9%	305 minutes (5 hours) **predicted from data*
50°C (122°F)	99.9%	200 minutes (3.33 hours) **predicted from data*
55°C (131°F)	99.9%	134 minutes (2.23 hours) **predicted from data*

Based on the typical conditions expected when heating the flight deck, <20% humidity is more applicable. For example, ambient conditions at 10°C (50°F) and 100% RH resulted in 10% RH when heated to 50°C (122°F). The impact that humidity has on SARS-CoV-2 shown in the tables above falls in line with empirical data in the scientific literature.[8]

Background: Airplane Thermal Limitations and Methods

Airplane components (e.g. materials and electronics) are designed to meet "military grade" thermal standards including MIL-STD-810 and DO-160. [redacted] internal standards provide further limits on expected thermal resistance based on analysis conducted by [redacted] equipment engineers. Most commonly, airplane components are designed to the following maximum temperature limits:

Table 5: Airplane Thermal Limits

	Operating	Non-Operating (unpowered)
Up to 60°C (140°F)	Indefinite exposure	Indefinite exposure
60 to 70°C (140-160°F)	No greater than 30 minutes	
70 to 85°C (160-185°F)	N/A	

Airplane Applications for Thermal Disinfection

Airplane flight decks are compact volumes with a variety of sensitive equipment that may not be certified for repeated exposure to traditional chemical spraying. Moreover, the vast quantity of knobs, switches, and topographical interfaces makes hand wiping tedious and presents a potential ergonomic risk. The compact space of airplane flight decks means there are a large number of touch sites that are hard to avoid due to design. The airplane flight deck thus becomes a potential source for coming in contact with contamination for the pilots and crew. The lower bacterial risk compared to other airplane locations along with the limitations of other disinfection methodologies due to the sensitive nature of the equipment makes the flight deck the ideal location for implementation of thermal disinfection.

There are technical challenges in implementing thermal disinfection at other locations such as the cabin, galleys, and lavatories. The amount of energy needed to heat and maintain the cabin at these temperatures along with the potential for dead zones (locations that air does not flow to and would not result in disinfection) make the cabin and galleys unpractical for thermal disinfection. Other means of disinfection that aren't applicable in the flight deck (such as electrostatic spraying) may be more viable and easily incorporated within the airplane cabin.

Within the lavatories and galleys, in many cases, increasing temperatures to the ranges presented here can lead to bacterial growth[9], potentially resulting in a less safe environment for the passengers. A variety of other disinfection methods are effective for a variety of viruses and bacteria with less potentially negative impacts.

Airplane Thermal Disinfection Methodology Selection

Autoclaves and other common high temperature thermal disinfection devices would damage equipment and materials on the airplane. Various methods of heating flight control surfaces to desired temperatures for disinfection have been evaluated for feasibility and are compared below. [redacted] down selected and proceeded with evaluation of the recirculating air heaters with exit temperature control.

Table 6: Evaluations of Thermal Disinfection Methods

Radiant heaters	Cannot achieve uniform surface temperature because of varying absorptivity and conductivity of surfaces.
Heater Blankets	Cannot achieve uniform surface temperature. Provide constant heat flux across surfaces with varying thermal conductivity.
Hot air blower	Handheld blowers are not feasible because of the extended amount of time required for thermal disinfection at temperatures safe for equipment and materials.
Heat with airplane Environmental Control Systems (ECS)	The airplane ECS is theoretically capable of supplying heat at temperatures for thermal disinfection, but the systems are specifically designed to prevent excessive cabin air temperatures for safety reasons.
Heat with external ground cart	Currently available ground carts have insufficient heating power to heat an entire airplane to disinfection temperatures, and no feature currently exists to direct ground air solely to the flight deck. Ground cart concepts also inefficient because hot air is blown *through* the volume being disinfected, meaning that expensively heated air must constantly leak from the airplane at the rate new air is supplied.
Heat with recirculating air heaters with exit temperature control	This is the concept chosen and tested by [redacted]. Air is recirculated to avoid blowing heated air out of the disinfection volume. Active controls limit the exit air temperature to match the equipment and material limits of the disinfection volume, preventing any surface from becoming overheated.

[redacted] Recirculating Heater Test Methodology

Based on lab efficacy testing data, recirculating heaters were designed and built by [redacted] for ground testing. Four 1.6 kW heaters were used with two >600cfm actively controlled fans. Figure 5 shows the recirculating heater concept. The heaters require active controls to limit exit temperature to 60°C to protect avionics in the flight deck. As such, the heaters were equipped with PID controllers rated to 60°C.

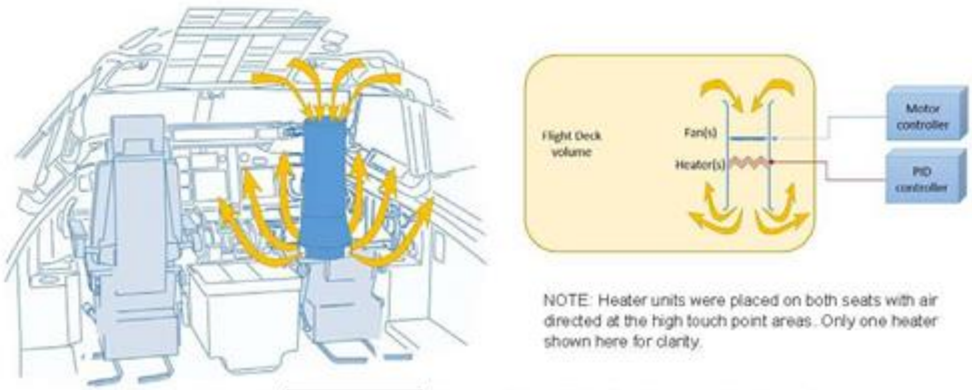

Figure 5: [redacted] Recirculating Heater Concept Schematic

These were utilized on a [redacted] to test the practicality of achieving a 40-60°C temperature range in the flight deck. Three rounds of testing were completed with modification to configurations and the heaters themselves after each round. Thermal disinfection temperatures were only achieved and maintained in the last round of test where the airplane was in the power off configuration.

[redacted] Recirculating Heater Test Results

Figure 6 shows the relationship between time and air temperature during the [redacted] testing for the third round of testing with the airplane powered off. With the airplane powered off, the airplane flight deck ramp up time was approximately 90 minutes. The fluctuations in the data can be correlated to external interferences in the flight deck when the door was opened. The control mechanism of the heaters was effective in ramping up to the require temperatures without resulting in overheating. Figure 7 shows thermal imaging across the flight deck during testing.

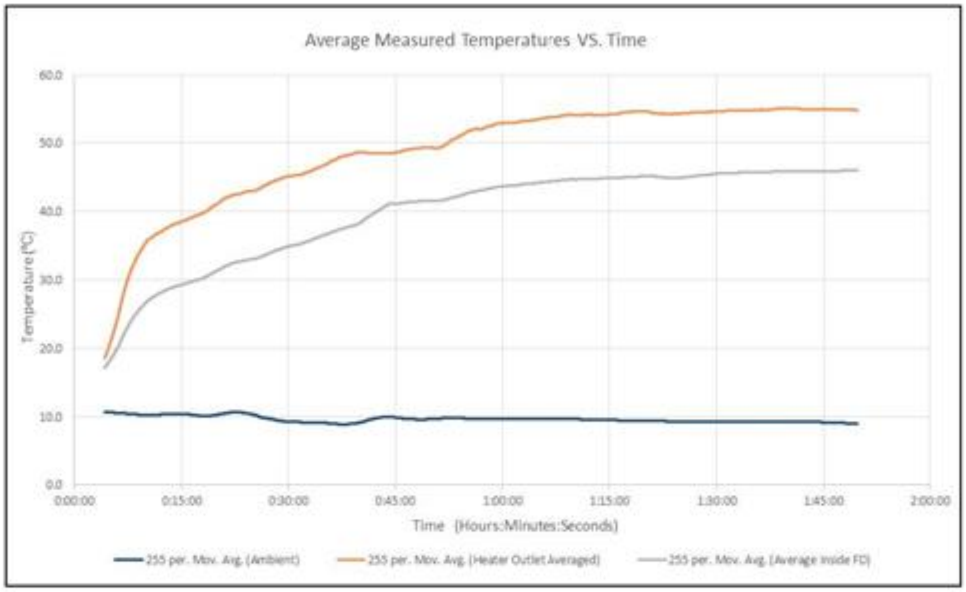

Figure 6: Relationship of Temperature and Time for Applicability Testing in [redacted] Flight Deck

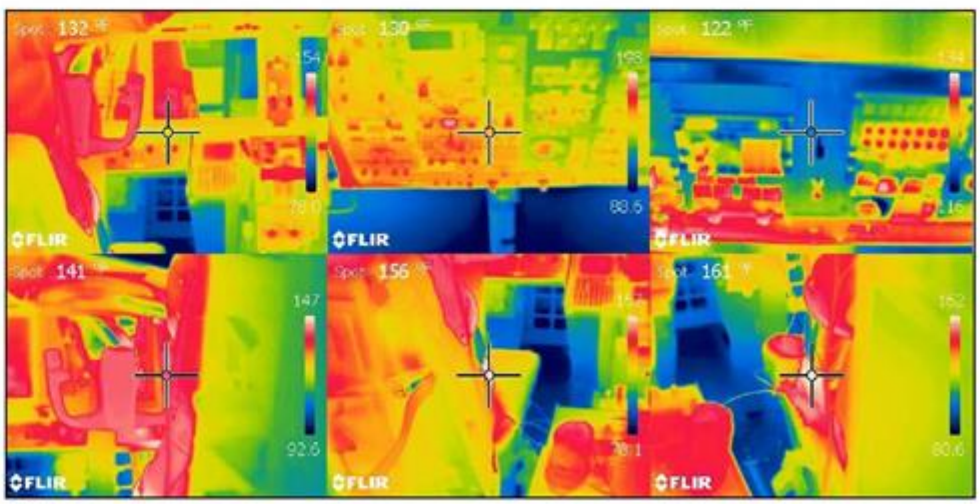

Figure 7: [redacted] Recirculating Heater Thermal Images

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All rounds of [redacted] testing provided insight. Below are the major findings.

- Flight Deck equipment is protected with active equipment cooling system fans that remove much of the added heat from the flight deck. It was determined that thermally disinfecting a *powered* airplane was not feasible with the equipment available during the test.
- As expected, environmental conditions played a significant role in the amount of time and energy needed to achieve the desired temperature range. Testing that occurred early in the summer resulted in faster temperature ramp up times. Than testing that occurred in late fall when outside temperatures were cooler.
- Subsequent testing using more advanced heaters on an *unpowered* airplane had better results. Removing power from the airplane disables the equipment cooling system, keeping the heated air within the airplane. Additionally, unpowered equipment is less thermally sensitive because it is not generating its own internal heat.
- The tests determined that it was possible to heat the flight deck to a disinfection temperature of 50°C (122°F) in approximately 90 minutes with an ambient temperature of 10°C (50°F) under cloudy conditions while the airplane was unpowered.
- Through testing, it was identified that the commercial grade heater controllers should be located outside the flight deck volume being disinfected if possible.
- Successful testing required active control of both heater power and fan air flow to ensure flight deck temperatures did not exceed the equipment's thermal limit of 60°C.

Conclusion and Application

The use of thermal disinfection in the flight deck was validated as a potentially viable methodology for inactivating the SAR-CoV-2 virus. As shown above, the flight decks on [redacted] airplanes are capable of withstanding repeated exposure to the time and temperature ranges required to inactivate the virus. Benefits of this technology include efficiency and ergonomic considerations. This is another one of the multi-layered solutions for disinfection that [redacted] has investigated.

In addition, [redacted] has identified the following considerations when using thermal disinfection:

- Operators must maintain 40°C for approximately 395 minutes, 50°C for 290 minutes, or 55°C for 224 minutes to achieve disinfection at expected flight deck humidity conditions (<20% RH). These times do include the time it takes to ramp up to these temperatures (ramp up time) of approximately 90 minutes as shown through [redacted] recirculating heating testing.
- In all but the warmest climates, thermal disinfection will require heat in excess of domestic power available at the typical jet way.
- The airplane should be unpowered during thermal disinfection. This reduces the risk of damage to avionics due to overheating and removes the heat loss due to the operation of the equipment cooling system.
- Disinfection with the airplane powered, if possible would require significantly more power and careful control of exit temperatures to protect avionics.

- Best results were obtained with a mix of variable speed fans and variable power heaters. Commercial grade heater controllers should be located outside the flight deck volume being disinfected.
- Efficacy tests conducted by the University of Arizona on SARS-CoV-2 determined the environmental conditions and times necessary to successfully inactivate 99.9% of the SARS-CoV-2 respiratory viruses.

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Airplane Heating Test for Thermal Disinfection of SARS-CoV-2

Introduction

SARS-CoV-2 is a new virus in humans causing respiratory illness that can easily spread from person-toperson.1 Breathing, talking, singing or coughing all propel particles through the air where they can then be inhaled by a nearby person, deposited on the skin or mucosal surfaces, or finally on surfaces in the surrounding area2. The mode of transmission is primarily through respiratory droplets, however transmission through contact with contaminated surfaces is possible.

The use of elevated temperatures (40°C to 60°C) to disinfect airplane locations that cannot be decontaminated as effectively through more traditional means, such as the flight deck, was evaluated. [redacted] determined that portable recirculating air heaters were the most viable method for airline use. In collaboration with [redacted], the University of Arizona conducted lab tests on SARS-CoV-2 to determine environmental conditions and times necessary to successfully inactivate 99.9% of the SARS-CoV-2 respiratory viruses.

A series of tests were run on a [redacted] 737 simultaneously to determine if thermal disinfection could be performed on a real airplane.

Thermal Disinfection Test #1, 2020-09-21

Summary

[redacted] conducted testing to validate a thermal disinfection procedure that will both meet the determined thermal temperatures for achieving an effective kill rate of SARS-CoV-2 and stay within the thermal operating conditions experience for the aircraft. During testing, the high level Airplane Configuration was as followed: Powered ON; Equipment Cooling ON; RECIRC Fans OFF, F/D temp control N/A.

The overall intent of the test was to validate that, by using relatively easily accessible equipment, an operator could heat up the flight deck to a temperature where thermal deactivation of the COVID-19 virus would be expected. To be operationally acceptable (would not take an insurmountable amount of time to deactivate), the temperature would be required to get up to 120F°-140F°. The goal was to reach a temperature of 130F° and hold for approximately 30 minutes. The outlet temperatures of the heaters were limited to 140F to ensure the equipment surface temp stayed well below environmental qualification requirements.

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Test Setup

The first phase of thermal capability testing used two bulk volume heaters rated to 1.5 kW each, based on guidance that this was the maximum power available at a typical jetway. Both heaters equipped with small fixed speed fans. Boost fans obtained to increase airflow through the system were found to be ineffective during test setup, and were not used.

The heaters were controlled by a single PID controller external to the flight deck volume which cycled heater power to control exit temperature as the temperature in the volume, and thus the heater inlet temperature, rose. The PID controller was driven by the average temperature of the two heater exits, resulting in a slightly different exit temperatures due to manufacturing tolerances. The exit air temperatures was set to slightly above 140 deg f (60 deg C), which was chosen to ensure the exit air temperature stayed well below the qualified ambient temperature environmental conditions of the flight deck equipment.

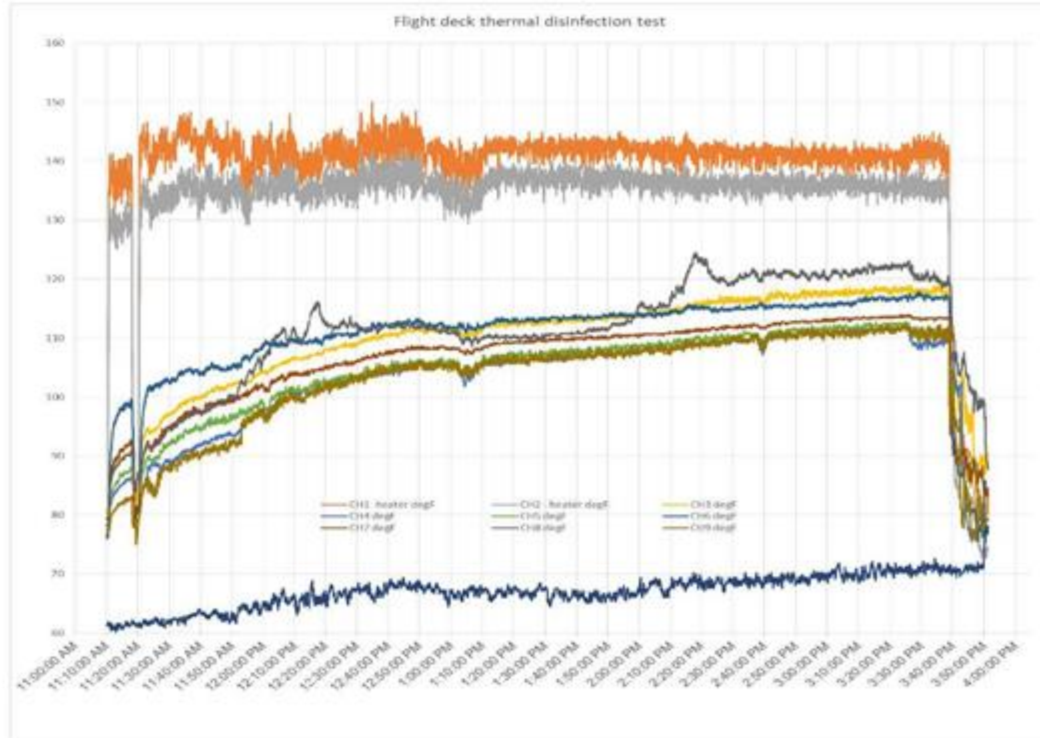
A total of 10 thermocouples were used during the test. One ambient sensor placed outside the aircraft, two at the heater outlet, and seven at various locations within the flight deck. A table of general thermocouple locations as well as a correlation to the data logger data is below.

Thermocouple #	Data logger channel	Location Description
6	10	Ambient (outside aircraft)
10	9	Top Right wall near flight deck entrance
2	8	First Officer handle near windshield
4	7	Captain's Right foot well
3	6	Rear of Center Counsel – Bottom right
8	5	Throttle #1
13	4	Captain headrest
1	3	First officer display
5	2	Left heater outlet
12	1	Right heater outlet

A 10 channel data logger was used to measure and record the thermocouple data throughout the testing. A FLIR 440 thermal imaging camera was also used to periodically measure flight deck surface temperatures for the duration of the test.

Results Summary:

A plot of thermocouple temperature by location is summarized below. The heaters were left on for a little over 4 hours and reached temperatures between roughly 110F°-120F° depending on location. Note that the dip in heater output temperature at approximately 11:20 A.M. was due to realization that the recirculation fans were left on "Auto". In turn, the foam door was removed, recirculation fans turned off, then the heaters turned back on.



Surface temperatures:

At the conclusion of the test, thermal images were taken throughout the flight deck to measure surface temperature at varying locations. Note that during this time the foam door was removed so temperatures may have decreased slightly from their peak value. In summary, surface temperatures from infrared measurements were shown to be between roughly 105F°-138F°.

Significant areas were too cool for thermal disinfection, while other areas were very close to flight deck equipment temperature limits. This was determined to be caused by insufficient air mixing due to inadequate fan power. The volume also heated very slowly, which was due in part to excessive heater cycling, also caused by the inadequate fans. A second test was planned with more powerful fans.

Thermal Disinfection Test #2, 2020-10-23

Test Setup

The second phase of testing using the same heaters with more powerful boost fans, sized such that no cycling would be expected to occur until the heater inlet temperature exceeded 120 deg F. Like the airplane electronic equipment, the fans were rated to operate at 140 deg F (60 deg C).

Each heater was equipped with an independent controller attached directly to the heater assembly, to simulate the expected airplane application format. Most commercial off-the-shelf PID controllers are only rated to ambient temperatures of 122 deg F (50 deg C). This test used the only one readily available controller was found which was rated to 140 deg F (60 deg C).

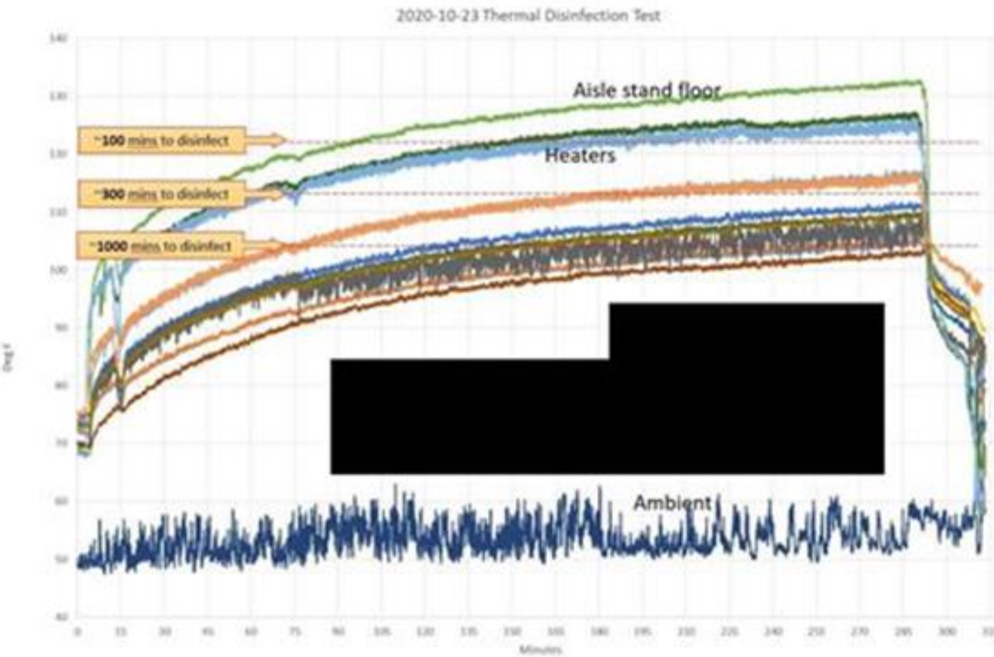
Supply voltage and amperage were measured for both heaters during this test. Although the heaters were rated to 1.5kW each, actual power usage was measured as slightly over 1.6kW per heater.

A total of 14 thermocouples on two data loggers were used during the test. One ambient sensor placed outside the aircraft, two at the heater outlet, and eleven at various locations within the flight deck. A table of general thermocouple locations as well as a correlation to the data logger data is below.

Thermocouple #	Data logger channel	Location Description
6	10	**Head/Chin Level/Captains Seat**
10	9	Top Right wall near flight deck entrance
2	8	First Officer handle near windshield
4	7	Captain's Right foot well
3	6	Rear of Center Counsel – Bottom right
8	5	Throttle #1
13	4	Captain headrest
1	3	First officer display
9	2	**Shin Level/Captains Seat**
7	1	**Seat Belt/Waist Level/Captains Seat**
Data logger #2		
-	1	Ambient
-	2	Right Heater
-	3	Left Heater
-	4	P5 Overhead

Results Summary:

A plot of thermocouple temperature by location is summarized below. Ambient temperatures for this test were 10 to 20 deg F cooler. The heaters were left on for a little less than 5 hours and reached temperatures between roughly 100F°-130F° depending on location. As before, there was a slight dip in performance at the beginning of the test, this time due to a minor wiring issue. No heater cycling was observed during testing – at all times the airflow was sufficient to prevent the heater outlet from exceeding equipment temperature limits.



Surface temperature:

At the conclusion of the test, thermal images were taken throughout the flight deck to measure surface temperature at varying locations. Temperatures were more even than the last test, but were also generally cooler. Most of the flight deck was too cool for timely thermal disinfection.

The [redacted] equipment cooling system design was reviewed and it was determined that even during ground operation, the E/E cooling system exhaust significantly more air than is supplied. (Most [redacted] airplanes have supply and exhaust approximately equal) It was hypothesized that much of the heat being generated by the heaters was being exhausted from the airplane through the equipment cooling exhaust system, and cold makeup air was being drawn into the open entry door and from there into the flight deck.

A third test was planned with the airplane unpowered, and with more powerful heaters.

Thermal Disinfection Test #3, 2020-11-19

Test Setup

For this test, the airplane was configured in a maintenance mode where all airplane power has been disabled except for lighting. This disabled the avionic heat loads in the flight deck, but also disabled the equipment cooling exhaust fans which were believed to have resulted in the poor performance on the previous test.

The third phase of testing used dual heater cores in each heater assembly. This abandons the prior assumption that thermal disinfection would be limited to available power at the jetway platform outside the entry door, which was assumed to the equivalent of two 15A 120VAC circuits.

The new assumption is that any thermal disinfection system would be powered instead from a ground cart or ground power, presumably 3 phase 220 VAC. For this test, four 15A 120 VAC circuits were used.

A large AC autotransformer (aka "Variac") was used to provide variable voltage to the fans. The intent was to initiate disinfection quickly on surfaces close to the heater exit by manually reducing the airflow to make the air exhaust match the desired exit air temperature – slightly above 140 deg F.

Another change to initiate disinfection during heating was that the heaters were redesigned to sit directly on the captain and first officer's seats, with exit air aimed directly at the surfaces being disinfected. This was expected to result in inadequate disinfection of the floor and surfaces below the seat level, but these areas are not assumed to be high contact touch points. *Flight Deck heater version 3*

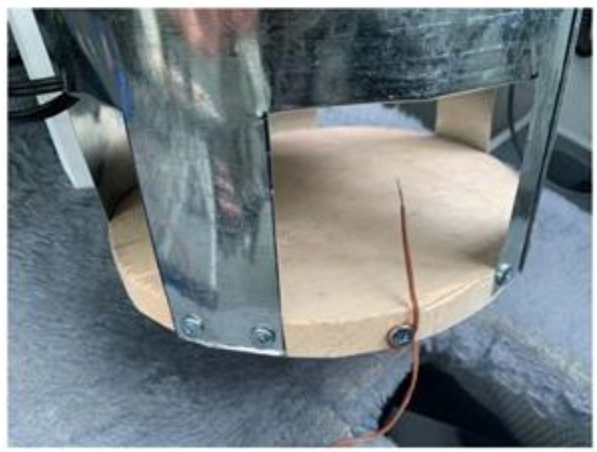
Note that with the airplane unpowered, thermal disinfection would theoretically be able to exceed 140 deg F (40 deg C) by a significant amount. For safety, given the use of commercial equipment, heater exit temperatures were limited to approximately 150 deg F (65 deg C).

The manual control on the fan air speed and lack of switching capability on the heaters proved to result in undesirable temperature fluctuations, and partway through the test, the previously used external PID controller was used to control one of the two heater cores in each heater. This proved to provide satisfactory control.

A total of 10 thermocouples were used during the test. One ambient sensor placed outside the aircraft, two at the heater outlet, and seven at various locations within the flight deck. A table of general thermocouple locations as well as a correlation to the data logger data is below.

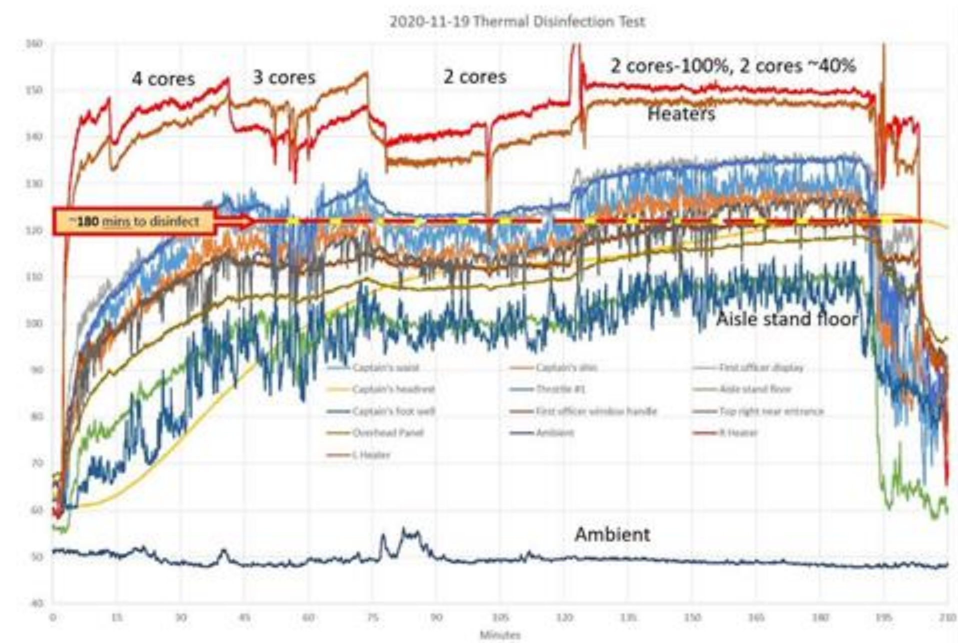
Thermocouple #	Data logger channel	Location Description
6	10	P5 Overhead
10	9	Top Right wall near flight deck entrance
2	8	First Officer handle near windshield
4	7	Captain's Right foot well

3	6	Rear of Center Counsel – Bottom right
8	5	Throttle #1
13	4	Captain headrest
1	3	First officer display
9	2	**Shin Level/Captains Seat**
7	1	**Seat Belt/Waist Level/Captains Seat**
Data logger #2		
-	1	Ambient
-	2	Right Heater
-	3	Left Heater



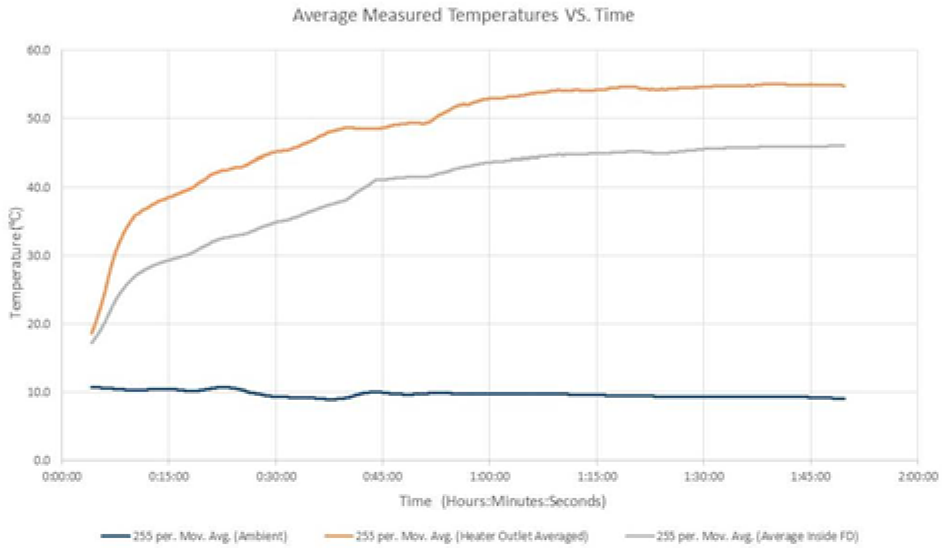
Results Summary:

A plot of thermocouple temperature by location is summarized below. The heaters were left on for a little over 3 hours and nearly all thermocouples reached or exceeded 120 deg F.



There are approximately 75 minutes with only 3 or 2 cores operating. If the PID controller had been used from the start, providing proportional control to one of the heater cores in each heater, it is believed that the 120 deg F could have been reached in as little as 90 minutes.

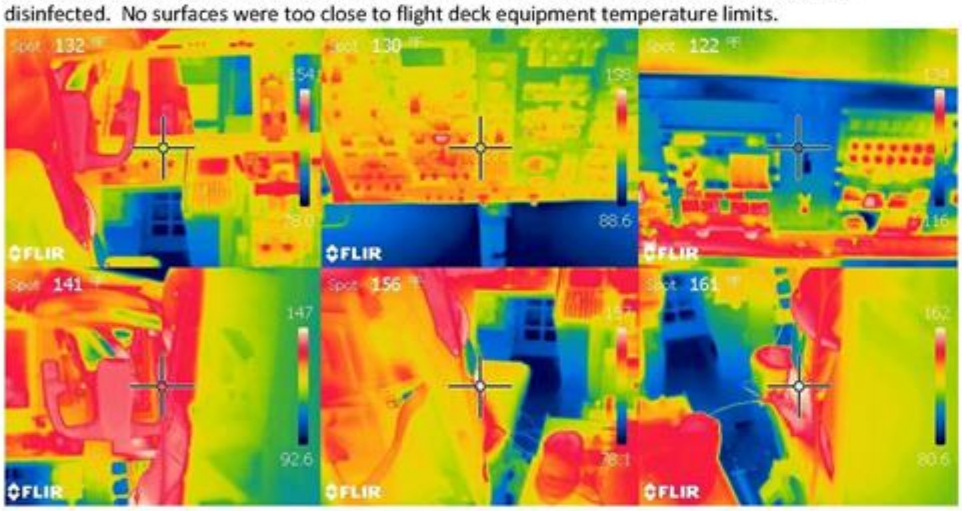
The next chart shows the running average of flight deck temperatures with this 75 minute period removed.



Average FD temperatures with 2 & 3 heater core times removed

Surface temperature:

At the conclusion of the test, thermal images were taken throughout the flight deck to measure surface temperature at varying locations. Surfaces measured with the thermal camera were generally warmer than the air temperatures, with nearly all surfaces in the range of 121-140 deg F (50-60 deg C). Some design changes would be required to ensure hot air is blown on all surfaces which need to be disinfected. No surfaces were too close to flight deck equipment temperature limits.



Selected thermal images at conclusion of test

Conclusions from this test:

Based on this successful test, the following determinations can be made:

- Flight Deck equipment is protected with active equipment cooling system fans that remove much of the added heat from the flight deck. It was determined that thermally disinfecting a powered airplane was not feasible with the equipment available during the test.
- As expected, environmental conditions played a significant role in the amount of time and energy needed to achieve the desired temperature range.
- Subsequent testing using more advanced heaters on an unpowered airplane had better results. Removing power from the airplane disables the equipment cooling system, keeping the heated air within the airplane. Additionally, unpowered equipment is less thermally sensitive because it is not generating its own internal heat.
- Disinfection with the airplane powered will require significantly more power, and careful control of exit temperatures to protect avionics.
- The tests determined that it was possible to heat the flight deck to a disinfection temperature of 50°C (122°F) in approximately 90 minutes with an ambient temperature of 10°C (50°F) under cloudy conditions while the airplane was unpowered.

- Commercial grade heater controllers should be located outside the volume being disinfected if possible.
- Successful testing required active control of both heater power and fan air flow to ensure flight deck temperatures did not exceed the equipment's thermal limit of 60°C.
- In all but the warmest climates, thermal disinfection will require heat in excess of domestic power available at the typical jetway.

Disinfection with Far-UV (222 nm Ultraviolet light)

Abstract

Ultraviolet light (light at wavelengths between 100nm and 400 nm) has well-known disinfection properties. These properties stem from the ability of UV light to damage the proteins and genomic material of bacteria and viruses through the disruption of chemical bonds. Most UV disinfection systems use germicidal lamps of wavelengths 240nm-280nm, with the most common being 254nm. Unfortunately, exposure to 254nm UVC light also causes damage to skin and eyes in humans.

However, recently published studies have demonstrated that UV light at 222nm has the same germicidal capabilities of 254nm light without damaging skin or eyes. The studies suggest that this may be due to the shorter UV 222nm wavelength (known as Far-UV, 200 to 235 nm) having reduced penetration depths in live tissue when compared with 254 nm light. While the effects on live tissue are diminished, Far-UV (222 nm light being the most prevalent) has <u>increased</u> efficacy for killing bacteria and viruses.

Like standard UVC, Far-UV light breaks pathogen (bacteria and virus) DNA bonds, which is the primary source of microbial deactivation. Combined with the small size of bacteria and viruses, when compared to mammalian cells, the short penetration depth of Far-UV successfully deactivates these pathogens. The current literature also points to more deactivation of bacteria at lower doses of 222nm light than that required for 254nm light.

This paper provides an overview of Far-UV 222 nm technology and its disinfection capability. Far-UV 222 nm is safer and more effective than the existing 250 to 280 nm UVC systems, with advantages that include reduced UV damage to skin and eyes, faster on/off times, more rapid disinfection, and the elimination of mercury from the lamp.

Introduction

An outcome of the COVID-19 pandemic is an increased need for safe, disinfected public spaces. It is imperative to reduce risk in the commercial aviation industry, which moved one billion people across the globe in 2019.[1] Widespread public concerns of the health risks of travel have not subsided, despite data that suggest that engineering controls such as high volume air recirculation substantially reduce the risk of disease transmission in flight.[2,3] Aircraft passengers will also continue to expect reasonable gate turnaround times, and competitive aircraft fares, even as more rigorous disinfection is required between flights. Thorough and efficient disinfection procedures must be implemented to return to prepandemic air traffic levels quickly and cost-effectively.

Although 254 nm light is the prevalent UV source in current disinfection devices, the SARS-CoV-2 outbreak has focused interest on the potential to instead use Far-UV light in the 200 to 235 nm range for disinfection. Specifically, disinfection with 222 nm light is an attractive alternative because unlike disinfection with 254 nm light, it has been shown in recent studies that 222 nm light kills pathogens (bacteria and viruses) without causing skin and eye damage.[4–8] According to these studies, the lack of hazard is due to the fact that Far-UV light has a penetration range of only a few micrometers when interacting with cellular system components and thus cannot reach the genetic material of living mammalian cells. Pathogens, being generally less than one micron in diameter, are fully penetrated by 222 nm light, resulting in killing of the pathogen.[7]

1. <u>The Difference Between Far-UV light and UVC light</u>

Ultraviolet (UV) is light at wavelengths shorter than 400 nm and greater than 100 nm as shown in Figure 1. UVA is nearly visible and is the UV waveband commonly called black-light [(Merriam Webster, 2020)]. UVB is a slightly shorter waveband and is a major factor in getting sunburned. Both UVA and UVB easily enter the earth's atmosphere and are present in daylight [(Merriam Webster, 2020)]. On the other hand, the UV wavelengths shorter than UVB are blocked by ozone in the earth's upper atmosphere and are not typically present in sunlight at the surface of the earth. This is important for germicidal effectiveness because it means pathogens have not evolved defenses against shorter UV wavelengths.

Figure 1: UV Spectrum

Depending upon the reference, the entire UV spectrum to the left of UVB might be called UVC. However, this paper uses a more precise definition of the UV spectrum that breaks the 200 to 280 nm Germicidal UV range into two subwavebands: UVC and Far-UV. UVC light is in the 240–280 nm region of the spectrum (254 nm sources being most prevalent) and Far-UV is in the 200 to 235 nm region (222nm sources being the most prevalent). Because shorter wavelengths have more energy than longer wavelengths, UVC and Far-UV are both effective at adding energy to molecules they contact, providing an absorbance target is available. It is this ability to add energy to molecules that gives UV light its germicidal properties.

The UVC waveband has been in use for germicidal disinfection for decades. Although UVC systems in the 250 to 280 nm range are now commercially available, most UVC systems currently available use a mercury vapor lamp to generate UVC light at 254 nm. Mercury vapor lamps were first developed for disinfection in the 1930s, and their use has grown over the last 60 years. Thus, the vast majority of public data on UVC disinfection is specifically data from 254 nm mercury vapor lamps.

Only recently have companies begun to develop and market lamps in the Far-UV waveband, with 222 nm being the most prevalent. The 222 nm wavelength is proving to be both safer and more effective than the existing 254 nm UVC systems.[4–8] Far-UV 222 nm system improvements over existing UVC 254 nm systems include: reduced damage to eyes and skin, faster on/off times resulting in more rapid disinfection, and the elimination of mercury (a toxic substance) from the lamp.

Effect of Wavelength on Pathogen Molecular Bonds

Photons from 235–280 nm UVC systems are absorbed by pathogen DNA molecules. The absorbance of UVC by the pathogen DNA causes specific DNA molecular bonds to fail. Because UVC primarily causes pathogen DNA damage, the individual microbe is not generally killed immediately. However, the pathogen DNA damage can prevent the microbe from replicating. For this reason a pathogen sterilized by UVC is refered to as "inactivated." In many cases the microbe can repair the DNA damage and "reactivate" itself using ordinary blue light in a process called photo-reactivation. The photoreactivation capability has been shown for a wide variety of bacteria and some viruses.[9] For this reason UVC data sometimes shows effectiveness both before and after reactivation.

Far-UV, on the other hand, is absorbed by both pathogen proteins and DNA. Although Far-UV is absorbed by pathogen DNA, its second pathogen kill mechanism is breaking the peptide bonds in the outer protein coating of single cell microbes and viruses. Pathogen protein absorbs 20 times more 222 nm Far-UV energy than 254 nm UVC energy for the same number of photons. Thus, pathogen protein bonds are 20 times more likely to fail due to the energy absorption from 222 nm light than 254 nm. This dual kill mechanism of both pathogen DNA damage and protein shell damage greatly increases the effectiveness of 222 nm Far-UV compared to 254 nm UVC and prevents microbes from photo-reactivation. Figures 2 and 3 show DNA and protein absorption rates for UVC and two commercially available Far-UV wavelengths at both 222 and 230 nm.

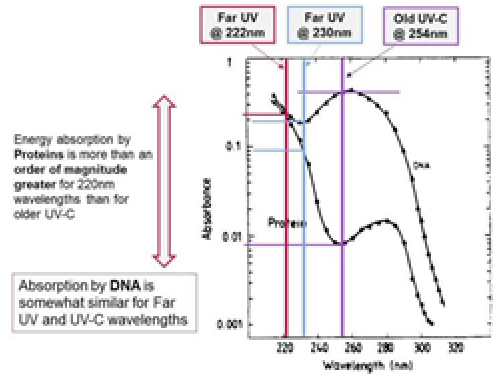


Figure 2: UV Absorption by Proteins & DNA ***(reproduced from Harm 1980)***

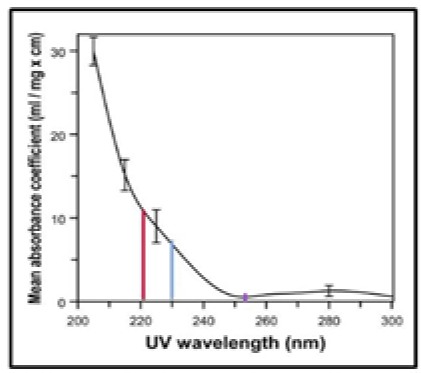


Figure 3: Mean wavelength-dependent UV absorbance coefficients, averaged over published measurements for eight common proteins

2. Far-UV light efficacy

UV dosage (also known as fluence) is measured in units of millijoules per square centimeters (mJ/cm^2). This dosage is the product of the intensity of the light and the exposure time. A millijoule (mJ) is one thousanth of a watt or milliwatt (mW) of power times one second of time. For example, 20 mJ/cm^2 can be achieved by projecting ten milliwatts of light power onto one square centimeter for two seconds.

The exact UV dosage required to kill or inactivate varies for specific pathogens and a specific wavelength of UV light. In general, the Far-UV 222 nm or UVC 254 nm dose is similar for most pathogens. Some pathogens require as little as two millijoules per square centimeter (~2 mJ/cm^2) of Far-UV or UVC to be killed or inactivated. A wide variety of pathogens can be killed or inactivated with less than twenty millijoules per square centimeter (~20 mJ/cm^2) of Far -UV or UVC light. The reduction of micro-organisms (either killed or inactivated) is classified using a logarithmic scale. A single log reduction is a 90% reduction of organisms. A two log reduction is a 99% reduction of organisms, followed by a three log reduction (99.9%), etc. For most applications, a three log reduction (99.9%) is sufficient to greatly reduce pathogen transmission.

Far-UV 222 nm Effectiveness Against Surface and Airborne Coronavirus

Both UVC and Far-UV wavelengths have been tested against a variety of pathogens. This paper focuses primarily for efficacy against coronaviruses.

Dr. David Brenner and others from Columbia University have been investigating 222 nm Far-UV efficacy against airborne human coronaviruses alpha HCoV-229E and beta HCoV-OC43[7]. According to their research, as shown in Figure 4, low doses of 1.7 and 1.2 mJ/cm^2 inactivated 99.9% (Log 3 reduction) of aerosolized coronavirus 229E and OC43, respectively.

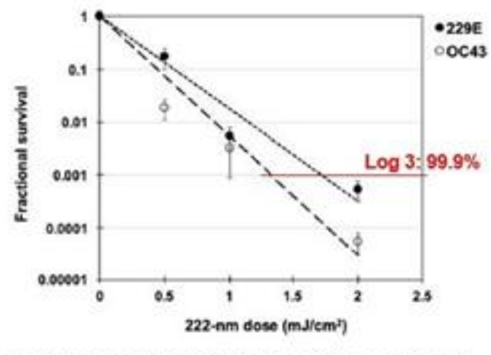


Figure 4: Coronavirus survival as function of the dose of Far-UV light. Fractional survival, PFUUV/PFU controls, is plotted as a function of the 222 nm Far-UV dose.

A related study published in the American Journal of Infection Control examined the effectiveness of Far-UV 222 nm against the SARS-CoV-2 virus on surfaces.[10] In this study, a Far-UV 222 nm dose of 3 mJ/cm^2 results in a 99.7% reduction in viable SARS-CoV-2 virus on a surface.

These two studies combined show that even a two to three mJ/cm^2 dose of 222 nm Far-UV will be effective in combating transmission of the virus responsible for COVID-19. This level of Far-UV is easily achieved using 222 nm lamps.

Additionally, [redacted] evaluated the efficacy of a Far-UV 222nm lamp against representative viruses and bacteria in a lab environment to get an indication of performance. A similar test was conducted with a prototype Far-UV 222nm system installed in a [redacted] ecoDemonstrator [redacted] flight test airplane in November 2019 to validate performance.

The efficacy target was a 99.9% pathogen reduction after one 5-second exposure. [redacted] was able to achieve 99.9% (log 3) reduction for all tested organisms, which included the following: *Escherichia coli* bacteria, *Pseudomonas aeruginosa* bacteria (planktonic and biofilm), the fungus *Aspergillus niger*, MS2 bacteriophage (surrogate for Norovirus), and the yeast *Rhodotorula mucilaginosa*. A reduction of 99.999% was achieved for *E. coli* and *planktonic P. aeruginosa*.

3. Far-UV 222 nm Technology Overview

All commercially available Far-UV 222 nm lamps have excimer lamps at their core. Excimer lamps are a lighting technology that excite a gas using high voltage electric discharges. Different gas mixtures generate different frequencies of light. Far-UV 222 nm light is produced by excimer lamps filled with a mixture of krypton (Kr) and chloride (Cl) gas (normally less than 3% chloride). These Kr/Cl excimer lamps can be made in many form factors, but are typically cylindrical.

Kr/Cl 222 nm excimer lamps eliminate the use of hazardous materials such as mercury. The 222 nm excimer lamps are reliable and can be expected to last thousands of hours. They are capable of handling high vibrations and high thermal temperatures. They can be turned on and off at full power instantly. The output intensity of the 222 nm light can be varied by changing the input power, allowing the lamp to be instantly brightened or dimmed as required. Excimer lamps can be run at power levels from as low as a few watts to kilowatts.

[redacted] Far-UV 222nm Applications

[redacted] developed a Far-UV 222 nm mobile wand prototype using a Kr/Cl cylindrical lamp, as shown in Figure 5, to address the near term need for a safe, hand-operated, fully mobile UV disinfection system for complex spaces where sensitive instrumentation may exist.

Figure 5: Kr/Cl 222 nm excimer lamp in [redacted] Far-UV 222nm mobile wand prototype.

The [redacted] Far-UV 222nm mobile wand prototype, when operated per instruction, will effectively sanitize high touch surfaces by a single operator, and be able to treat an area such as the flight deck in less than 15 minutes. It is capable of producing the 3 mJ/cm^2 needed for SARS-CoV-2 disinfection in a fraction of a second at operational ranges.

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This is in contrast to standard UVC 254 nm mercury bulbs, which require a significant warm-up time to reach full illumination power and contain the toxic chemical mercury. Mercury is not allowed on commercial aircraft without a waiver from the FAA, making mercury lamps difficult to qualify for aircraft use.

[redacted] verified the system safety, material compatibility, and efficacy of the Far-UV 222 nm excimer bulb system used in the [redacted] mobile wand prototype. This included performing a series of exposure tests to individual electronic components from the [redacted] flight decks using brand-new units in controlled environments simulating both the power-on and power-off states. [redacted] also evaluated material compatibility, electromagnetic interference (EMI) and ozone levels.

Prior to the Far-UV 222 nm mobile UV wand development effort, *The* [redacted] *Clean Cabin Fresh Lavatory* (Figure 6) was a product development study in 2016 that explored the use of a Kr/Cl 222 nm excimer lamps in a lavatory setting to disinfect the lavatory after every use. The learning and the technology developed for that project contributed significantly toward the rapid development of the [redacted] FarUV 222 nm mobile wand prototype.

Figure 6: [redacted] *product development concept of Far-UV 222 nm implementation in a* [redacted] *lavatory*

4. Safety of Far-UV 222 nm

All cell walls are made from protein and Far-UV wavelengths between 200 and 230 nm interact strongly with proteins. Multiple university studies have demonstrated that 222 nm light typically will not penetrate deeper than three microns into the surface of a cell wall.[5] In the case of pathogen microbes, their diameter is typically 0.1 to 1 micron. Thus, they are fully penetrated and destroyed. Human cells, in contrast, are generally more than 40 microns in diameter and are not fully penetrated by 222 nm UV light. These studies have shown that the outer layer of the skin and the tear layer of the eyes form a protein shield for the cells beneath.[5]

Additional university studies on the safety of mammalian skin and eye exposure to 200 to 235 nm Far-UV wavelengths have been conducted. The collective body of data indicates Far-UV wavelength does not cause skin or eye damage. A 60 week study of hairless mice exposed eight hours a day to 222 nm light is being conducted by Columbia University. The current data from the study indicates no skin or eye damage over the 60 weeks.[11]

Government Regulatory UV Exposure Limits

There are no US Government regulatory UV radiation exposure limits. However, a non-governmental organization, the American Conference of Governmental Industrial Hygienists (ACGIH), publishes Threshold Limit Values (TLVs), which are recommended exposure limits over an eight-hour day and are widely used as a guideline. The UV exposure limits are wavelength dependent, ranging from 3 mJ/cm^2 to 100,000 mJ/cm^2.

Figure 7 shows the current TLVs for UV wavelengths. Note that although 222 nm light is often more effective against pathogens than light in the 254 to 270 nm range, the TLV is much higher. The TLV for 222 nm, 254 nm, and 270 nm is 23, 6, and 3mJ/cm2 respectively. Since the coronavirus disinfection dose is approximately 3mJ/cm2, at 270 nm the disinfection dose and the threshold limit for human exposure are the same. This implies that even incidental exposure to 270 nm light may exceed the Threshold Limit.

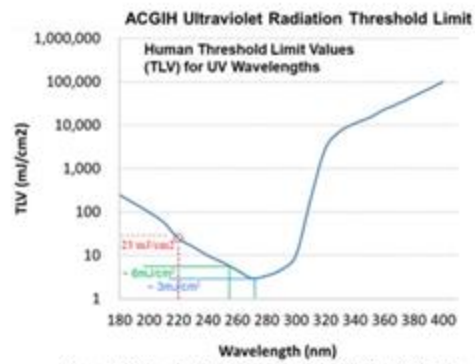

Figure 7: Threshold Limit Values (TLVs) for UV Light

The current TLV for 222 nm light does not reflect the recent data indicating that Far-UV (200 to 235 nm) light does not cause the DNA lesions, erythema, photo-keratitis, and other associated effects of 254 nm light exposure. The American Conference of Governmental Industrial Hygienists (ACGIH) is currently reviewing the 222 nm safety data with the goal of revising the TLV upward for 222 nm light. Progress toward this revision is ongoing. Although studies have shown 222nm light is safer than 254 nm light, use of appropriate personal protective equipment (PPE) remains necessary when using high powered 222 nm systems until the ACGIH revises the TLV.

Ozone Generation

All UV lights generate some level of ozone and so care must be taken accommodate that. Most of the ozone generated by 222 nm excimer lamps is a result of high voltage interaction at the outer electrodes. This can be mitigated by placing the lamp behind a sealed UV transparent glass. In addition, some ozone

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is generated by 222 nm photon interaction with air. This is generally mitigated by air exchange.

5. <u>Summary</u>

Ultraviolet (UV) light in the 222 nm wavelength has the same germicidal capabilities of 254 nm light to kill or inactivate pathogens (bacteria and viruses) without the same damaging effects of 254 nm exposure on the skin or eyes. This is due to the shorter UV wavelengths (known as FarUV, wavelength 200 to 235 nm), that have reduced penetration depths in live tissue when compared with standard UVC (240 to 280 nm) light. While the effects on live tissue, such as skin and eyes, are diminished, Far-UV (222 nm light being the most prevalent) has <u>increased</u> efficacy for killing bacteria and viruses.

Like standard UVC, Far-UV light breaks pathogen DNA bonds. In addition, Far-UV is highly effective at breaking protein bonds in the membrane shells of pathogens, including SARS CoV-2. This same protein interaction makes Far-UV 222 nm much safer for human exposure, including: reduced UV damage to skin and eyes, faster on/off times, more rapid disinfection, and the elimination of mercury from the lamp.

[redacted] ***recently entered into patent and technology licenses with Healthe® Inc. and FarUV Technologies. Under these licenses, both companies will produce and distribute a commercial Far-UV 222 nm mobile wand, helping airlines and potentially others reduce the impact of the coronavirus pandemic.***

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Summary of Display Cover Glass Exposure to Disinfectants

[redacted]

10/14/20

Objective

- In response to customer requests to use specific chemicals on display products for the purpose of disinfection, [redacted] conducted exposure testing on display assets and components. The primary intent of this testing was to assess the effect of these chemicals / or method of disinfection on the first surface coatings. All coatings tested were on [redacted] products.
    - A list of chemicals of interest was generated and attempts were made to obtain each one. However, not all chemicals on the list were obtainable.
    - The plan included both visual and optical test assessments before and after exposures were completed

Initial Chemical List to be Evaluated

• [redacted] Cleaning Process	Kit Available & Tested
• ~~Zip Chem Calla 1452~~	Not Available
• ~~Zip Chem AeroDis 7127~~	Not Available
• Sani-Cide EX3	Available & Tested
• ~~Matrix #3~~	Not Available
• ~~NetBiokem DSAM~~	Not Available
• Ozone	Completed
• Vital Oxide	Available & Tested
• Diversey OxiVirTB	Available & Tested
• Ecolab APeroxide Multisurface	Available & Tested
• M-Zone Wipes – Micronova	Available & Tested

Status

Chemical / Process	Conclusion - Optical Test	Conclusion - Visible
• [redacted] Process*	Pass @ 100 exposures	Pass @ 100 exposures
•Sani-Cide EX3	Fail @ 10 exposures	No visible changes after 10 exposures
•Ozone	Pass @ 168 hours of exposure	Visible changes @ 168 hours
•Vital Oxide	Marginal @ 10 exposures; Fail @ 100 exposures	No visible changes after 100 exposures
•Diversey OxiVirTB	Fail @ 10 exposures	No visible changes after 10 exposures
•Ecolab APeroxide Multisurface	Fail @ 10 exposures	Visible changes after 10 exposures
•M-Zone Wipes – Micronova	Marginal @ 10 exposures; Fail @ 100 exposures	Visible changes @ 100 exposures

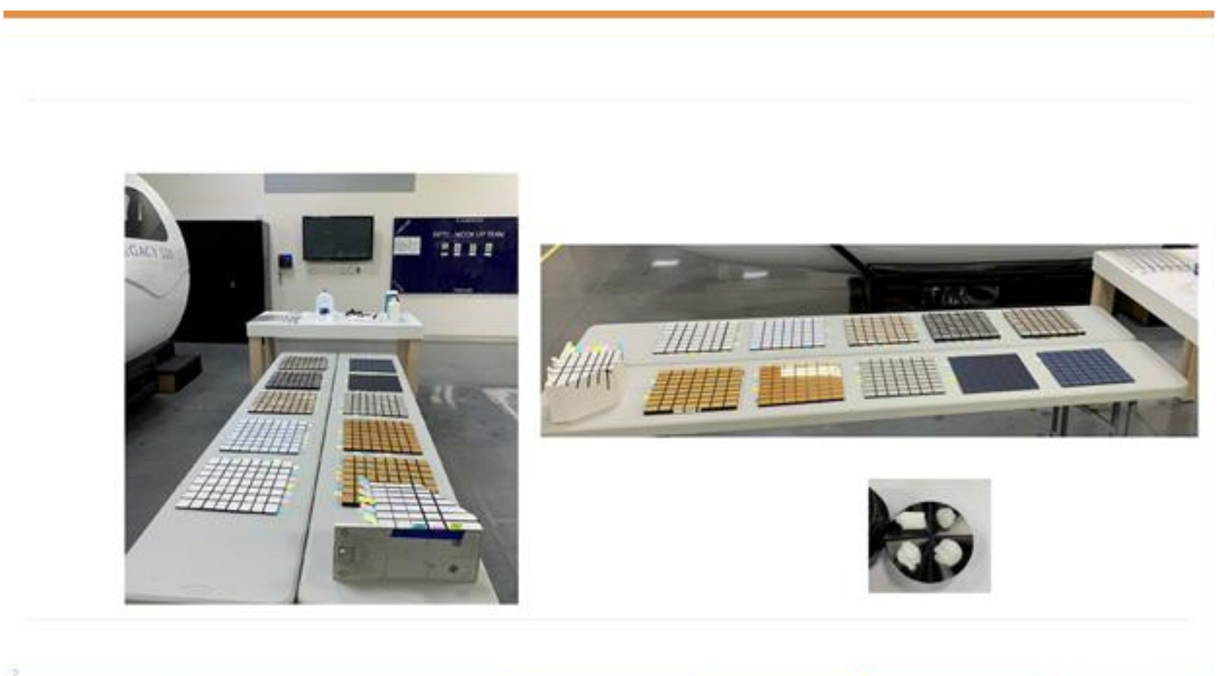
*Cleaning process only; higher % IPA required to disinfect

Overall Conclusion

- NO additional disinfection methods were identified in this study for optical coatings on [redacted] display products
- The [redacted] cleaning kit (CPN 005-8414) resulted in passing results in both optical and visible evaluation. All others evaluated in this study failed in one way or another
  - This kit currently contains a 50% mix of isopropanol (IPA) and 50% de-ionized water. Note this is below the recommended 70% IPA set forth by CDC to disinfect against COVID-19. [redacted] makes no representations or warranties regarding the effectiveness of its products in disinfecting against COVID-19.
  - It is known IPA at full strength will not degrade the coatings.
  - It is important to note that a cloth suitable for clean-room use is required, such as a microfiber cloth.
  - When cleaning, IPA should be applied directly to the cloth to be used. IPA shall not be applied directly to the product.

5

C Original equipment manufacturer 3 documents



Test Procedure

Test Interior Finishing as per:

- ASTM F2109 for Qualification by International STD (Pass/Fail)
- ASTM 1452 (MPA) for internal validation (test beyond the minimum)

ASTM F2109:

- Valid for: Painted Aluminum / Tedlar / Vinyl / Leather / Naugahyde (synthetic leather)
- It will be included: Varnish, Plating, Carpet and Fabric

	Application Method	ASTM F2109	ASTM 1308 - Embedded Cotton Balls					
		Immediate Removal after rubbing 25 times	15 min	1 hour	6 hours	12 hours	24 hours	48 hours
PRODUCTS	PRODUCT 1							
	PRODUCT 2							
	PRODUCT 3							
	PRODUCT 4							
	DISINFECTANT BRAND 1							
	DISINFECTANT BRAND 2							
	DISINFECTANT BRAND 3							

Round 1: Products available to general public

Isopropyl Alcohol (IPA) - 70% (Listed by EPA) | Hydrogen Peroxide 3% (Listed by EPA) | Germ - X Hand Sanitizer (Listed by EPA) | Clorox Disinfectant Wipes (Listed by EPA)

Materials after tests


Paint over composite
FME


Veneer High Gloss Varnishing
F/List


Veneer High Gloss Varnishing
FME


Light Beige Natural Leather
Aeristo


Dark blue Natural Leather
Townsend


Blue Natural Leather
Spinneybeck


Cream ultraleather
Tapis


Light grey ultraleather
Tapis


Beige Fabric
AIP


Dark Carpet
Kalogridis


Beige Carpet
Scott


Window panel - Polycarbonate
FACC

Degradation type

Strong degradation on leather


Blue Natural Leather
Spinneybeck

Cleaning Curling


Beige Fabric
AIP

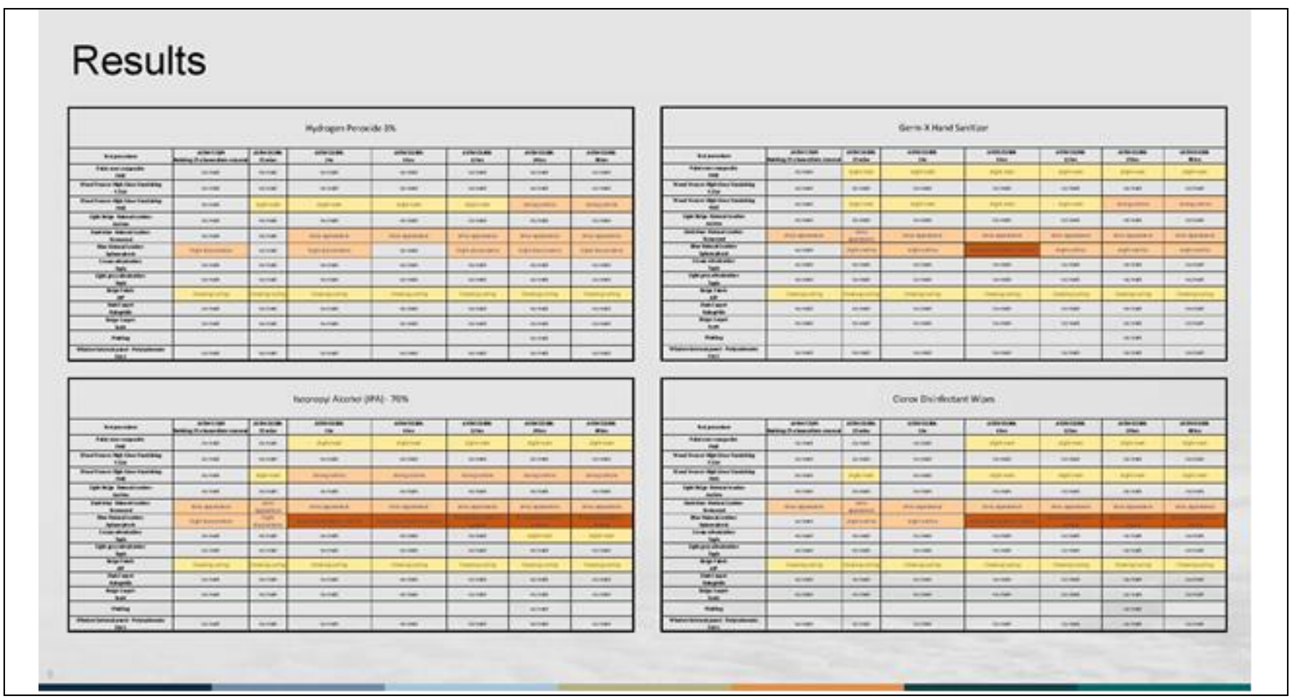
Marks outline


Veneer High Gloss Varnishing
FME

Results (ISOPROPYL ALCOHOL – IPA 70%)

Isopropyl Alcohol (IPA) - 70%

Test procedure	ASTM F2109 Rubbing 25 x immediate removal	ASTM D1308: 15 mins	ASTM D1308: 1 hr	ASTM D1308: 6 hrs	ASTM D1308: 12 hrs	ASTM D1308: 24 hrs	ASTM D1308: 48 hrs
Paint over composite FME	no mark	no mark	slight mark	slight mark	slight mark	slight mark	slight mark
Wood Veneer High Gloss Varnishing F/List	no mark	no mark	no mark	no mark	no mark	no mark	no mark
Wood Veneer High Gloss Varnishing FME	no mark	slight mark	strong outline	strong outline	strong outline	strong outline	strong outline
Light Beige Natural Leather Aeristo	no mark	no mark	no mark	no mark	no mark	no mark	no mark
Dark blue Natural Leather Townsend	shiny appearance	shiny appearance	shiny appearance	shiny appearance	shiny appearance	shiny appearance	shiny appearance
Blue Natural Leather Spinneybeck	Slight discoloration	Slight discoloration	strong discoloration + outline	strong discoloration + outline	strong discoloration + outline	strong discoloration + outline	strong discoloration + outline
Cream ultraleather Tapis	no mark	no mark	no mark	no mark	no mark	slight mark	slight mark
Light grey ultraleather Tapis	no mark	no mark	no mark	no mark	no mark	no mark	no mark
Beige Fabric AIP	Cleaning curling	Cleaning curling	Cleaning curling	Cleaning curling	Cleaning curling	Cleaning curling	Cleaning curling
Dark Carpet Kalogridis	no mark	no mark	no mark	no mark	no mark	no mark	no mark
Beige Carpet Scott	no mark	no mark	no mark	no mark	no mark	no mark	no mark
Platting						no mark	
Window internal panel - Polycarbonate FACC	no mark	no mark	no mark	no mark	no mark	no mark	no mark



PRELIMINARY CONCLUSION

Application with soft cottom cloth embed with the Disinfectant

CONCLUSION	Materials compatibility evaluation		COVID EFFECTIVE
APPROVED	1	HYDROGEN PEROXIDE 3%	EPA list (kept in surface for 20 min)
REPROVED	2	Germ-X Hand Sanitizer	no evidence
REPROVED	3	Isopropyl Alcohol (IPA) - 70%	EPA list
REPROVED	3	Cloro Disinfectant Wipes	EPA list

Microshield 360 evaluation

- Microshield 360 product applied by Constant Aviation

Renew application (video)

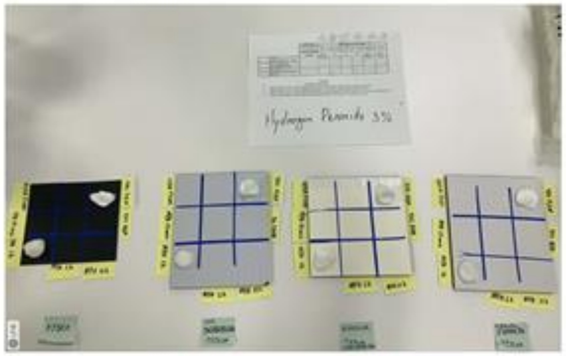
Antimicrobial application (video)


Microshield Results
Required additional step for streaks removal with dry cloth
Reference
MS360 treated
Aging tests: temperature variation:
- No major variations observed compared to reference samples with or without the Microshield 360


Additional Executive Jets materials tested
▪ Hydrogen Peroxide 3%
Cockpit dado panel paint
Seat Base metallic paint
No effect observed in any of the materials tested

Commercial finishing materials tests

- Hydrogen Peroxide 3%



No effect observed in any of the materials tested

Commercial finishing materials tests

- Microshield

Boeing Test

constant

Boeing D6-7127 Revision M (April11,2003)

11.3.1	Sandwich Corrosion	Conforms
11.3.2	Immersion Corrosion Test	Conforms
11.3.3	Rubber Test	Conforms
11.3.4	Sealant Test	Conforms
11.3.5	Painted Surface Test	Conforms
11.3.6	Tedlar Surface Test	Conforms
11.3.7	Vinyl Surface Test	Conforms
11.3.8	Fabric and Carpet Test	Conforms
11.3.9	Leather and Naugahyde Test	Conforms
11.3.10	Flash Point Test	Informational
11.3.11	Polycarbonate Crazing Test	Conforms

MicroShield 360 Passed the Boeing D6-7127 Standard for Cleaner/Disinfectant

Your Nationwide MRO Solution

Next actions

✓ Production treatment approach - ongoing

- H2O2 – disinfection prior to send the aircraft for delivery and cockpit prior to production flights, as required
- To create a disinfection NE for Executive Jets interiors

✓ AMM update - NL for executive jets – ongoing

- H2O2 application with wet cloth
- Caution note for no spray

✓ Microshield 360 – approved

- Flammability substantiation will be provided by supplier

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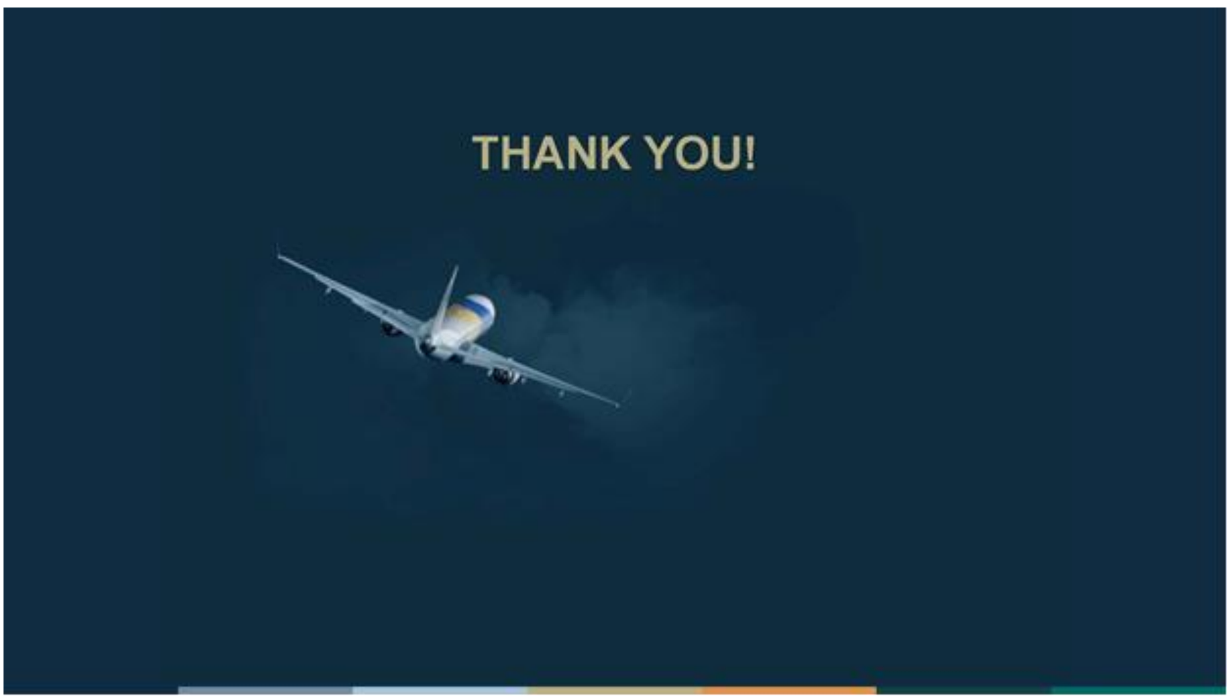

REPORT No.: [redacted]

PROGRAM: [redacted]

TITLE: UV-C tests on Cockpit flight deck

ATA 2200 No.: 00-00-00

CLASSIFICATION: PRIVATE

REVISION SHEET AND APPROVAL LIST

ISSUE: -
DESCRIPTION Initial Release.
The electronic signatures of this report are shown on its approval list that shall be printed from the Technical Reports Database.

TABLE OF CONTENTS

1 SCOPE

This document presents the Ultraviolet C (UV-C) compatibility tests, for all [redacted] aircraft, performed to verify UV-C radiation (wavelength 254nm) compatibility with flight deck components.

2 APPLICABLE DOCUMENTS

- EFFECT OF UV-C ON AIRCRAFT INTERIOR MATERIALS - Version 2, September 25, 2020 - [redacted]

3 CONCLUSION

The components presented no visible degradation when exposed under 20 J/cm² of UV-C radiation (wavelength 254nm).

4 PROCEDURE

4.1 MATERIAL

- Brown paper
- Aluminum tape
- Plate of UV-C lamps
- Radiometer
- Wood pieces for support
- Stopwatch
- PPEs (gloves, long sleeve shirt or jacket and protection goggle)

Radiometer data:
Manufacturer: Delta Ohm
Model: HD2302.0
SN: 20018098

UV-C lamps device is composed by 3 UV-C lamps of 254nm of 18W each, see Figure 1.

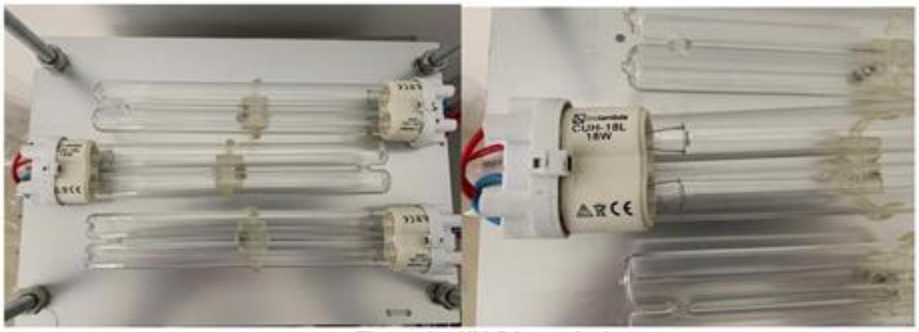

Figure 1 – UV-C lamp device

4.2 TEST SETUP

1. Cover the surround components not tested with brown paper.
2. Cover the non-metallic components under test with aluminum tape and identify each strap of tape with the energy to be tested on the component surface under this strap (see Figure 2). Identification shall be 0, 3, 10 and 20 equivalent to the energy in J/cm².
3. Place UV-C lamp plate over the identified components under test.
4. Add the radiometer at the level of components under test
5. Turn on UV-C lights and calculate the irradiance displacing the UV-C lamps plate of the same height of radiometer sensor (40mm in this test), wait for measure stabilization (see Figure 3). The radiometer shows irradiance values in a scale of micro-Watts/cm².
6. Register the stabilization time
7. Return the UV-C lamps plate to position

Figure 2 – Test Setup - push buttons and guards

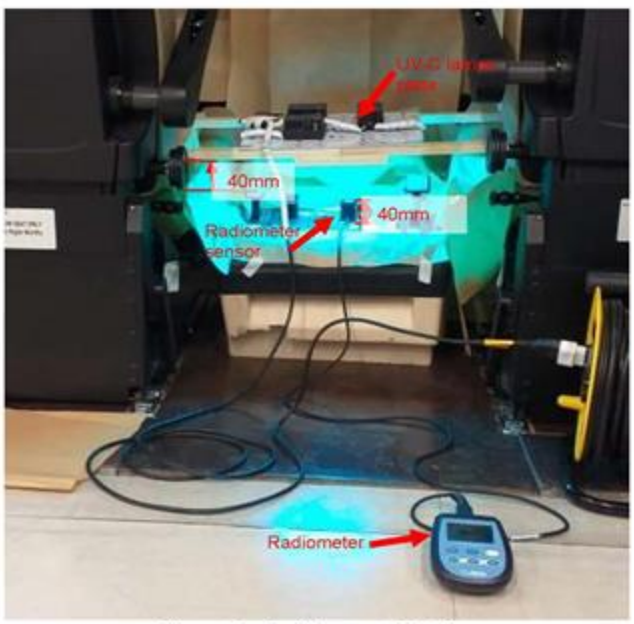

Figure 3 – Irradiance calculation

4.3 TEST PROCEDURE

1. Remove aluminum tape strap related to 20 J/cm².

2. Place a brown paper in front of UV-C lamps, blocking the light to the components under test.
3. Turn on the UV-C lights.
4. After the stabilization time achieved, remove the brown paper and start the time count to achieve 10J/cm².
5. Once achieved the time equivalent of 10J/cm² energy accumulated, remove the aluminum tape strap related to 10 J/cm².
6. Start the time count to achieve 7J/cm².
7. Once achieved the time equivalent of 7J/cm² energy accumulated, remove the aluminum tape strap related to 3 J/cm².
8. Start the time count to achieve 3J/cm².
9. Once achieved the time equivalent of 3 J/cm², turn off UV-C lights. Remove the aluminum tape strap related to 3 J/cm².
10. Compare results with ambient light.

See Table 1 for the summary of each step of UV-C exposition.

Table 1 – summary of energy applied on the test

Step	Area uncovered	Energy exposed per step	Total Energy accumulated
1	20 J/cm²	10 J/cm²	10 J/cm²
2	10 J/cm²	7 J/cm²	17 J/cm²
3	3 J/cm²	3 J/cm²	20 J/cm²

4.4 ACCEPTANCE CRITERIA

No crazing or visual changes in colors of tested components. Small changes can be accepted based on judgement of the test witness.

5 RESULTS

5.1 TEST 1 - PUSH BUTTONS, PLASTIC GUARDS AND KNOB:

For this test it was selected the buttons and guards from engine fire panel and pitch buttons and yaw knob from trim panel. Levers from flap, speed brake and park brake were left uncovered and exposed to the total energy of 20J/cm².

The shutoff 1 and 2 pushbuttons and guards were divided in 4 areas of test: Shutoff 1 was divided with 0 J/cm² energy (reference) in the top and 20 J/cm² energy in the bottom, while Shutoff 1 pushbutton was with 10 J/cm² energy (reference) in the top and 3 J/cm² energy in the bottom

Bottle A and B pushbuttons were also divided in 4 areas: Bottle A was divided with 0 J/cm² energy (reference) in the top and 20 J/cm² energy in the bottom, while Bottle B pushbutton was with 10 J/cm² energy (reference) in the top and 3 J/cm² energy in the bottom. PITCH DN and UP pushbuttons were also divided in 4 areas: PITCH DN was divided with 0 J/cm² energy (reference) in the left side and 20 J/cm² energy in the right side, while PITCH UP was divided with 10 J/cm² energy (reference) in the left side and 3 J/cm² energy in the right side.

YAW knob was divided in 2 areas: 0 J/cm² energy (reference) in the left side and 20 J/cm² energy in the right side.

See Figure 4 for the areas identification in engine fire and trim panels.

Figure 4 - Test setup for test 1

The irradiance was registered as 8.773 mW/cm², see Figure 5.

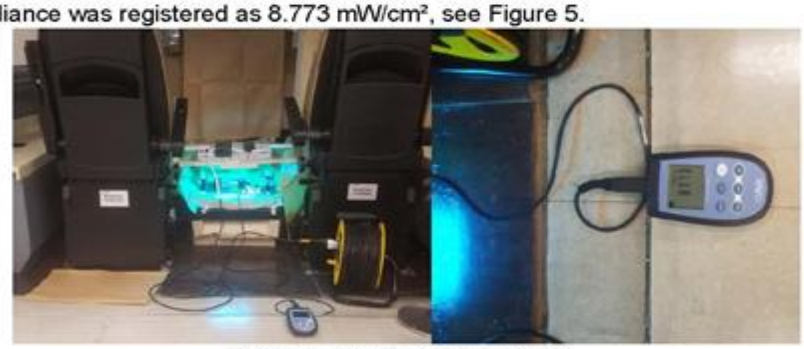

Figure 5 - Irradiance calculation

Using the irradiance data, it was possible to calculate the following time for the test shown in Table 2:

Table 2 – Energy applied and calculated time test 1

Step	Area uncovered	Energy exposed (per step)	Time exposed (per step)	Time exposed (total)
1	20 J/cm²	10 J/cm²	19 min	19 min
2	10 J/cm²	7 J/cm²	13 min 18 sec	32 min 18 sec
3	3 J/cm²	3 J/cm²	5 min 42 sec	38 min

The Figure 6 shows the partial result after step 2 of Table 2 is completed.

After test completion, it is possible to observe no visible change comparing components subjected to different levels of energy, see Figure 7.

Figure 6 - Components from test 1 after 17 J/cm² of energy applied

Figure 7 – Components from test 1 after test completion.

5.2 TEST 2 - CAUTION AND WARNING PUSHBUTTONS AND KNOBS:

For this test it was selected the buttons for warning and caution and avionics knobs close to it. The components from left side were tested to 0 and 20 J/cm², and components from right side were tested to 3 and 10J/cm², see Figure 8 for energies zones identified. Figure 9 shows the UV-C lights applied for test 2 right side, during lamps warm-up (stabilization).

Figure 8 – Test 2 setup – Energy zones identification

Figure 9 – Test 2 – UV-C lamp warm-up

Using the irradiance data for test 2, it was possible to calculate the following time for the test shown in Table 3 for components of lef side (20 and 0 J/cm² of energy) and Table 4 for components in the right side (10 and 3 J/cm² of energy):

Table 3 –Energy applied and calculated time test 2 left side

Step	Area uncovered	Energy exposed (per step)	Time exposed (per step)	Time exposed (total)
1	20 J/cm²	20 J/cm²	1h24 min	1h24 min

Table 4 –Energy applied and calculated time test 2 right side

Step	Area uncovered	Energy exposed (per step)	Time exposed (per step)	Time exposed (total)
1	10 J/cm²	7 J/cm²	14 min 34 sec	14 min 34 sec
2	3 J/cm²	3 J/cm²	6 min 15 sec	20 min 50 sec

The Figure 10, Figure 11 and Figure 12 presents respectively the final results for left side and right side components

Figure 10 – Test 2 – results for 0 and 20 J/cm²

Figure 11 - Test 2 – results for 3 and 10 J/cm²

Figure 12 - Test 2 – results for 0 and 20 J/cm² - Warning and Caution pushbuttons

5.3 TEST 3 - LEATHER

For this test it was selected the pilot seat. The components were tested to 0 and 20 J/cm, see Figure 8 for results. No visual change was observed in this color of leather.

D Original equipment manufacturer 4 documents

DATE: December 8, 2020

SUBJECT: [redacted] Ultra-Violet Light (UV) System Benefits

1. Introduction: [redacted] has released its second-generation UV system for use in aircraft and other transportation systems such as rail, metro, and ships/ferries. This second-generation system adds additional UV power and flexibility while reducing size, weight and cost. This paper provides a summary of UV performance and safety requirements.

2. UV Performance

a. The [redacted] UV system has been found in a clinical study to achieve greater than 99.9% reduction of tested pathogens.[1] In on-aircraft testing the [redacted] UV system was found to achieve greater than 99.9% reduction of the tested pathogen on tested tray tables, cabin seating arm rests and lavatory seat, armrest and wash basin.[2]

b. The second-generation [redacted] UV system comes equipped with 14 UVC 253.7nm wavelength low pressure mercury lamps (eight 95W and six 35W). When properly applied, UVC irradiation has been found to reduce pathogens - including tested bacteria and viruses - on multiple surfaces and in multiple environments.[3,4,5] A collection of publications identified in the References section of this document indicate reduction rates as high as 90.0% - 99.9999% on certain bacteria and viruses when irradiated at specified dosages.

c. Multiple clinical studies on the efficacy of 253.7nm UVC light on SARS-CoV-2, the virus which causes COVID-19, have been performed. Boston University has reported achieving a 99% reduction with a dose of 5 mJ/cm^2 in its testing. It is still too soon to know definitively whether UV light will be effective against COVID-19 outside the clinical environment, but testing is on-going, and we have reason for optimism.[6]

d. The [redacted] UV system has been tested and shown capable of delivering doses ranging from 9.6 – 39.0 mJ/cm^2 at a speed of 10 rows/minute when applied to aircraft surfaces including seating surfaces, tray tables, windows, overhead bins and lavatories.[7]

3. UV Safety – Operators

a. A third-party safety evaluation has been performed for the second-generation [redacted] UV system which finds that the system can be operated safely with no short or long-term health impacts when adequate Personal Protective Equipment (PPE) is used appropriately.[8]

b. Organizations such the International Commission on Non-Ionizing Radiation Protection and national/local organizations set standards for UV exposure and worker PPE. Users of the [redacted] UV systems must be familiar with and follow all applicable regulations, policies and procedures for their region and country of use.

c. Consistent with the foregoing, the potential risk areas are the eyes and skin areas such as hands, face and neck. These areas can be protected by appropriate work clothes including long sleeve shirts. The hands can be protected by wearing gloves. Suitable headwear will protect the head and neck. Goggles, mask, visors or face shields, which absorb UVR, should be worn as a precaution against potential eye hazard associated with UVC. As indicated in 3.b., always consult applicable regulations, policies and procedures for the region and country of use.[8]

4. UV Safety – Aircraft

[redacted] has tested for UVC impact on a wide variety of aircraft materials including but not limited to seating materials, plastics, window and IFE covers, cockpit systems and seat belts. Testing included an assessment of potential impacts to flame retardancy, strength, and color/appearance. Materials tested for flame retardancy and strength exhibited no significant impact. Potential for color or appearance changes depend on the material and accumulated dose – many materials show no change at any tested dosage, and some show fading or yellowing after specified dosages and periods of use. Seat headrests showed the soonest change due to proximity of the UV system wing lights, with color changes starting at 4 years of use when using the system once per day. Most materials showed no noticeable change until greater than 10 years of use (when using once per day).[7]

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EFFECT OF UV-C ON AIRCRAFT INTERIOR MATERIALS

Version 2, September 25, 2020

Effect of UV-C on Aircraft Interior Materials

Table of Contents

Effect of UV-C on Aircraft Interior Materials

Executive Summary

The purpose of this paper is to provide data on the effects of ultraviolet (UV-C) light, generated by the [redacted] UV Cabin System, on materials inside an aircraft cabin. The [redacted] system uses 253.7 nanometers (nm) UV-C light. To support introduction of this new system, [redacted] 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 [redacted] UV Cabin System. [redacted] 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.

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[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.

[redacted] UV Cabin System and Applied Dose

Figure 1: [redacted] UV Cabin System

The [redacted] 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 [redacted] 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 [redacted] UV Cabin System at positions corresponding to many locations in a typical narrow body aircraft. The measurements were made by placing an ILT800CUV 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.

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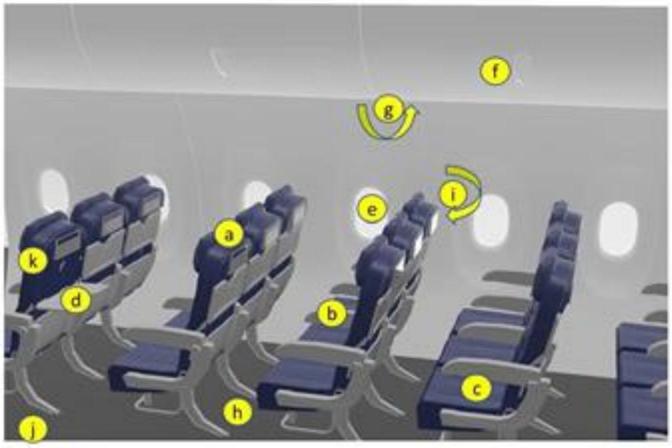
[2] "Aircraft Bacteria & Virus Reduction Using UVC Lighting", white paper issued May 2020, [redacted].

Effect of UV-C on Aircraft Interior Materials



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

Effect of UV-C on Aircraft Interior Materials

Materials testing was completed in June - September 2020 at the [redacted]. 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

Effect of UV-C on Aircraft Interior Materials

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 exposures provided the dose.

Figure 4: Reactor used for UV-C materials stability

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 [redacted].

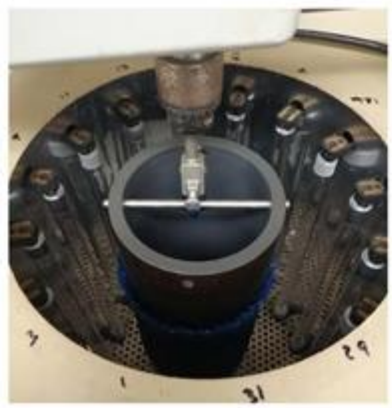


Figure 5: Reactor with material stand and motor

Seat belt strength was measured by [redacted], according to SAE standards[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).

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 change
Boltaron	No significant change	---	Slight change
IFE screens	---	---	No significant change
Polycarbonate window covers	No significant change	No significant change	Slight change
Décor foils	---	---	Slight 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 2: Strength for Sateen Leather (No significant effect)Table 3: Flame Retardancy for Sateen Leather (Passes Test)

ExposureExposure (J/cm (J/cm^2)^2)	Flame Time (sec)Tensile Strength (l lbf)	Drip Time (sec)Trapezoid Tear Strength	Burn Length (in)
00	0 61.5	0	17.6 1.3
7627	0 54.4	0	18.9 1.0
19154	0 54.1	0	17.9 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)

7

Effect of UV-C on Aircraft Interior Materials

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/cm² 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/cm²)	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/cm²)	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

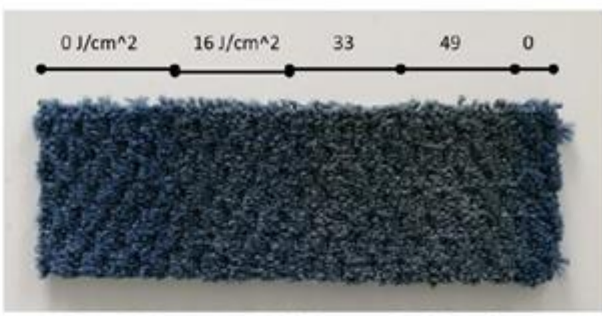


Figure 7: Progressive UV-C Exposure for Nylon Carpet

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/cm², 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/cm²	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/cm²)	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.

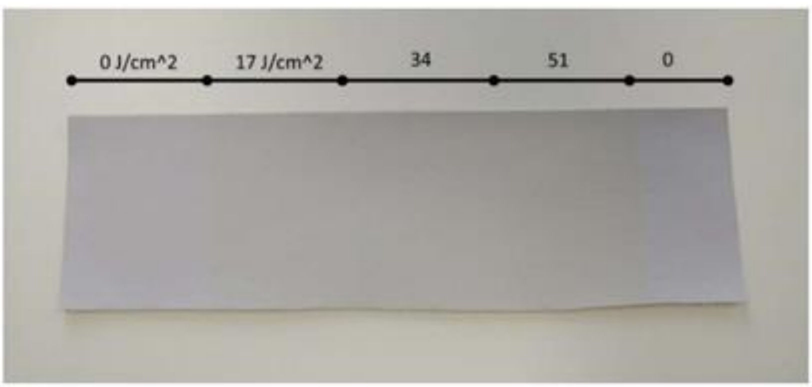


Figure 8: Progressive UV-C Exposure for Columbia Synthetic Leather

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

Effect of UV-C on Aircraft Interior Materials

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.

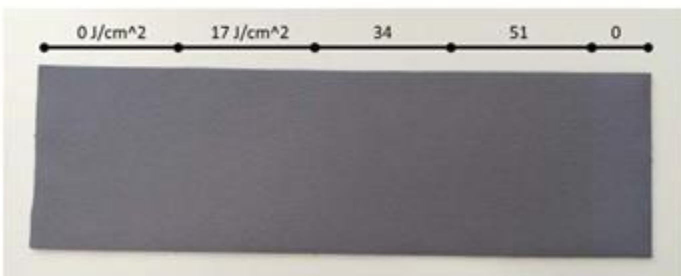


Figure 9: Progressive UV-C Exposure for Luxaire Synthetic Leather

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

Effect of UV-C on Aircraft Interior Materials

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.

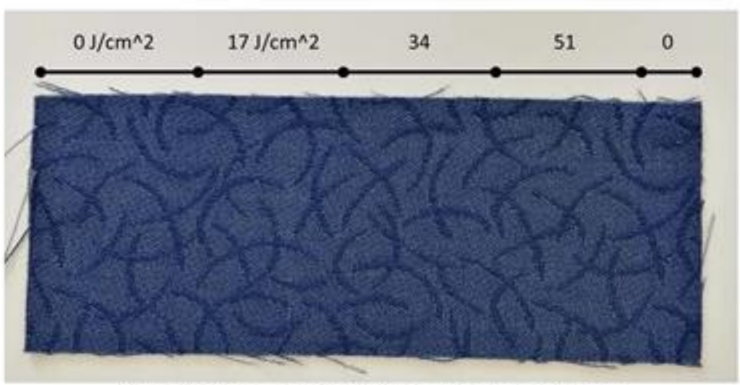


Figure 10: Progressive UV-C Exposure for Wool-Polyester

Effect of UV-C on Aircraft Interior Materials

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

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

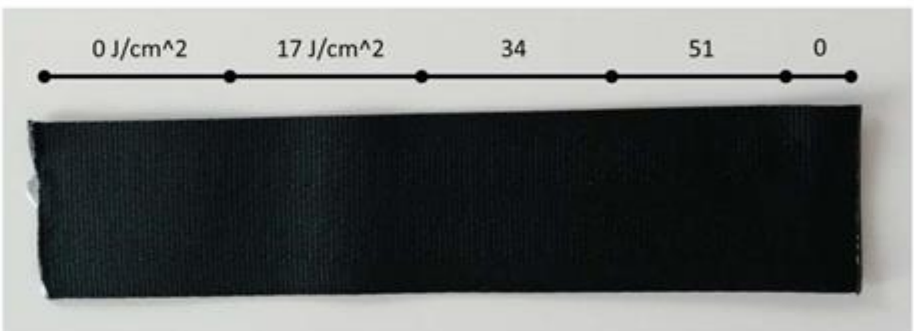


Figure 12: Progressive UV-C Exposure for Polyester Seat Belt Webbing

Effect of UV-C on Aircraft Interior Materials

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.

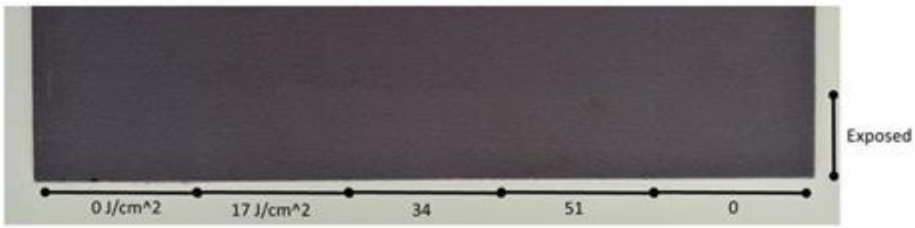


Figure 13: Progressive UV-C Exposure for Kydex

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.

Effect of UV-C on Aircraft Interior Materials

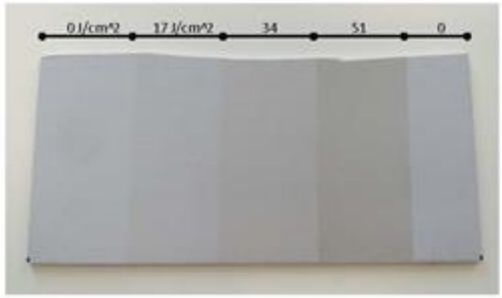


Figure 14: Progressive UV-C Exposure for Boltaron 9815N

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 [redacted] test chamber and were exposed using the progressive masking technique. [redacted] 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.

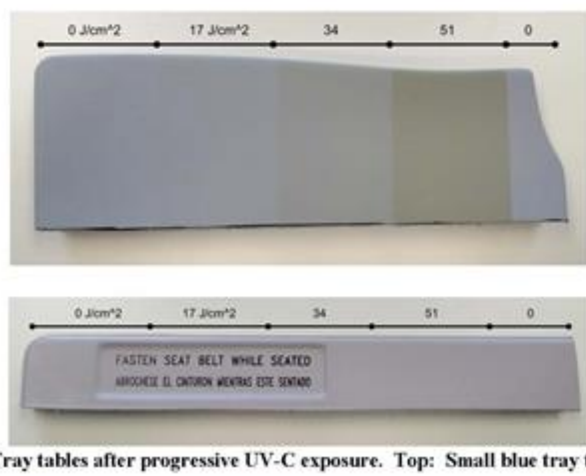


Figure 15: Tray tables after progressive UV-C exposure. Top: Small blue tray table, Bottom:

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 [redacted] 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

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/cm²). 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

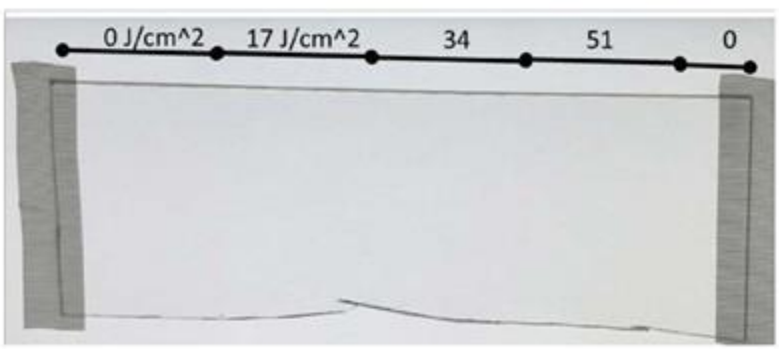


Figure 17: Prolens polycarbonate after progressive UV-C exposure

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.

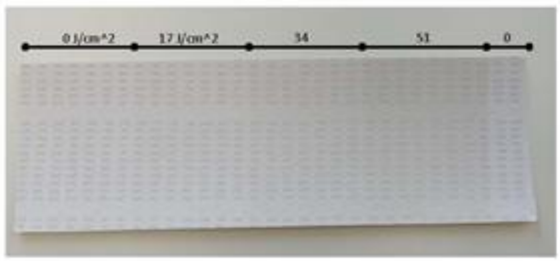


Figure 18: Schneller decorative foil laminate (P/N S3863)

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 [redacted] 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. [redacted] 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.

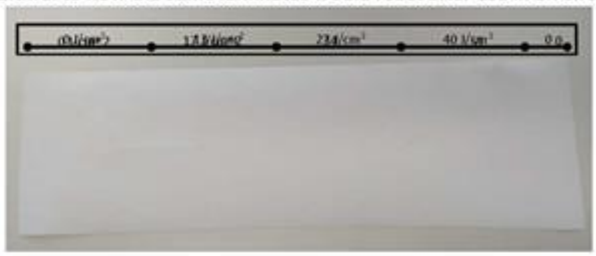


Figure 21: Sample A

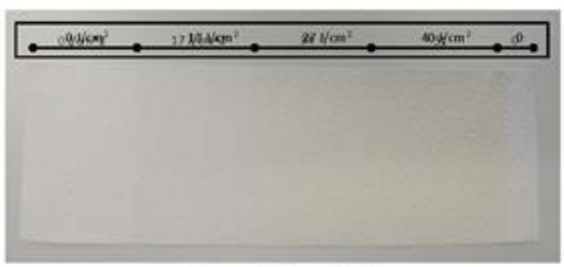


Figure 22: Sample B

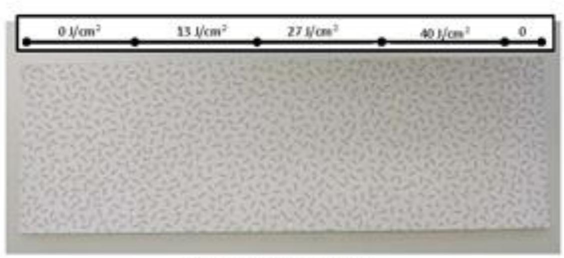


Figure 23: Sample C

Figure 24: Sample D

[redacted] TSC 2.0 Cockpit Touch Screen Display

The TSC 2.0 is a [redacted] 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/cm² to 20 J/cm². 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/cm² 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: [redacted] **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

[redacted] 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: [redacted] 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.

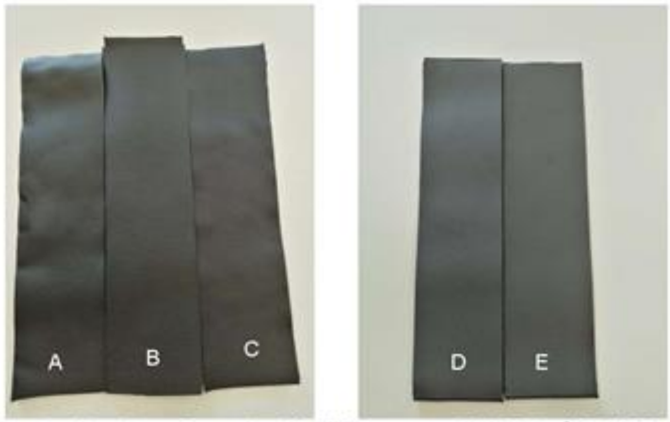


Figure 27: Leather Seat Coverings. Group 1: A No UV-C exposure, B 185 J/cm², C 365 J/cm²; Group 2: D No UV-C exposure, E 365 J/cm²

Table 20: Flame retardancy results for leather seat coverings

Group	Exposure (J/cm²)	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.

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/cm². Using our measured UV-C dose of 9.4 mJ/cm² (one treatment equals two exposures at 30 rows/min treatment speed), a cumulative dose of 19 J/cm² 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/cm². 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.

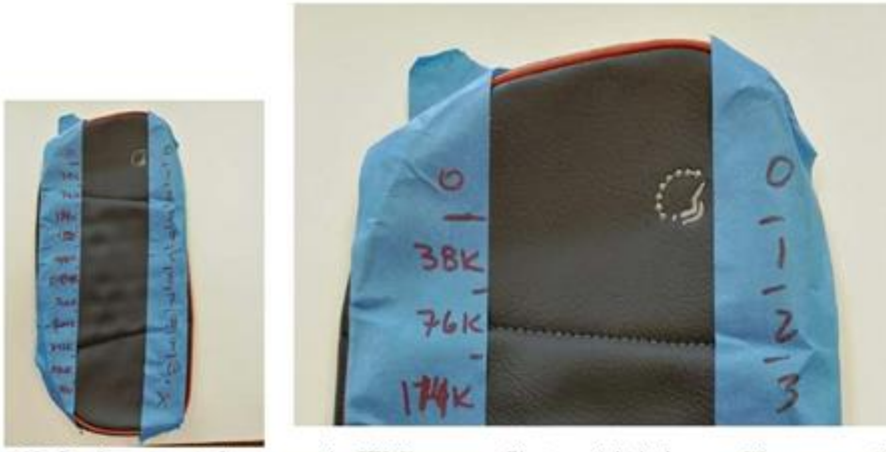


Figure 29: Leather armrest after progressive UV-C exposure. Photo on right is close up of the upper portion of the left photo, with UV-C dose marked.

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

Effect of UV-C on Aircraft Interior Materials

The sample was then exposed to a total dose of 48.5 J/cm², 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/cm²:

Band 0: 0 J/ J/cm², original, no exposure
Band 1: 4 J/cm²
Band 2: 8 J/cm²
...
Band 10: 40 J/cm²

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/cm², with 4 J/cm² 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

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.

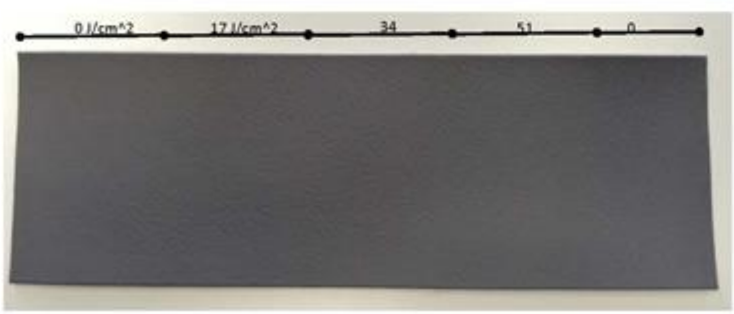


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Figure 34. Ultrafabrics 492-6022FR12 Hydra (Gray), Progressive Exposure

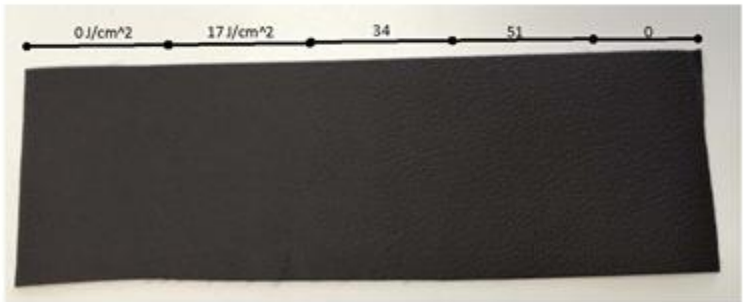

Figure 35. Ultrafabrics 590-5012FR12 Zephyr (Black), Progressive Exposure

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

Effect of UV-C on Aircraft Interior Materials

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 $[\frac{ml}{cm^2}]$	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 $[\frac{ml}{cm^2}]$	
005	75	06/20	ABL757-1-005			
006	76	06/20	ABL757-1-004			
007	77	06/20	ABL757-1-009	2 years	9000 $[\frac{ml}{cm^2}]$	
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 $[\frac{ml}{cm^2}]$	
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 $[\frac{ml}{cm^2}]$	
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 $[\frac{ml}{cm^2}]$	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 $[\frac{ml}{cm^2}]$	
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/cm² and 45 9 J/cm² UV-C exposures.

Table 25: Schroth Seat Belt Flame Resistance – 9 J/cm² 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	

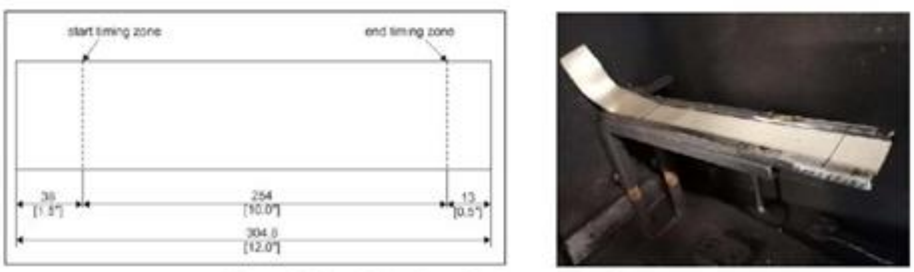

Figure 37. Seat Belt Flame Resistance, Test Set-up

E Original equipment manufacturer 5 documents

Aircraft disinfection

Summary of test results
SARS-CoV-2

June 04, 2021

Content

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4. Appendix - Summary tables for disinfection results

1. Efficacy of disinfection methods:

In order to reduce the viral burden in an aircraft, different physical parameters for the inactivation of SARS-CoV-2 (temperature and relative humidity) were tested in a cell culture-based assay. The results should help to implement the modeling for the inactivation kinetics under different environmental conditions and incubation times. In addition, the identified parameters were tested with a surrogate virus. The lower risk classification of this surrogate virus enabled the evaluation of different physical and chemical inactivation procedures in an aircraft-cabin-dummy (cabin zero).

1.1 Method and materials

Experiments involving SARS-CoV-2 were all carried out in the [redacted]. The virus was applied to the provided sample pieces and incubated for the indicated time at different temperatures and different relative humidity values. The virus was then recovered by suspending the residual or dried virus with cell culture medium. The residual viral activity was tested in cell culture by staining infected cells with a SARS-CoV-2 specific antibody. The positive cells were counted and the "focus forming units" were calculated.

Experiments involving PRRSV were all carried out in [redacted]. The virus was applied to the provided sample pieces and incubated for the indicated time at different temperatures and different relative humidity values. The virus was then recovered by suspending the residual or dried virus with cell culture medium. The residual viral activity was tested in cell culture by monitoring the development of a cytopathic effect (CPE). The CPE results in detachment of the cells, after fixation and staining positive wells were counted and the "tissue culture infective dose 50" (TCID50) was calculated.

In order to test the viability of SARS-CoV-2 on different surfaces, two different sample materials were provided by [redacted]. One was a seatbelt buckle made of metal, the other was a tray table made of plastic (Figure 1).

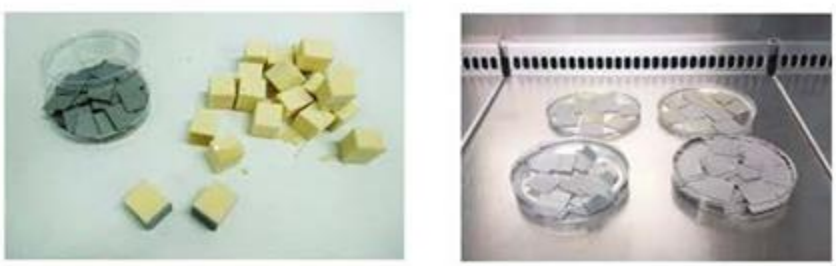

Figure 1

a) The tray table samples were provided as 2 x 2 cm pieces. The foam material in the middle was removed and discarded and the plastic pieces on the top and bottom were put in 70 % Ethanol for sterilization.

b) Pieces of metal (left) and plastic material (right) soaked in 70 % Ethanol in sterile Petri dishes.

The materials used for the experiments are listed below:

- Vero E6 cells for assays involving SARS-CoV-2
- SARS-CoV-2 (isolate BetaCoV/Germany/BavPat1/2020 p.1)
- Marc 145 cells for assays involving PRRSV
- PRRSV (isolate porcilis, attenuated vaccine strain)
- Sample material 2 x 2 cm (provided by [redacted])

1.2 Results for SARS-CoV-2 laboratory experiments with thermal disinfection:

1.2.1 Variation of temperature

Three temperatures were tested: 35°C, 40°C and 65°C. In this experimental setup, the relative humidity varied with the temperature. The temperature and relative humidity measurements were recorded for each experiment using a data logger that was included in the device. The measurement of parameters was recorded each second.

Five incubation times were tested: 0 minutes, 15 minutes, 30 minutes, 60 minutes and 120 minutes.

Only one surface was tested. Because of the lower titer reduction in previous experiments, the plastic material was chosen.

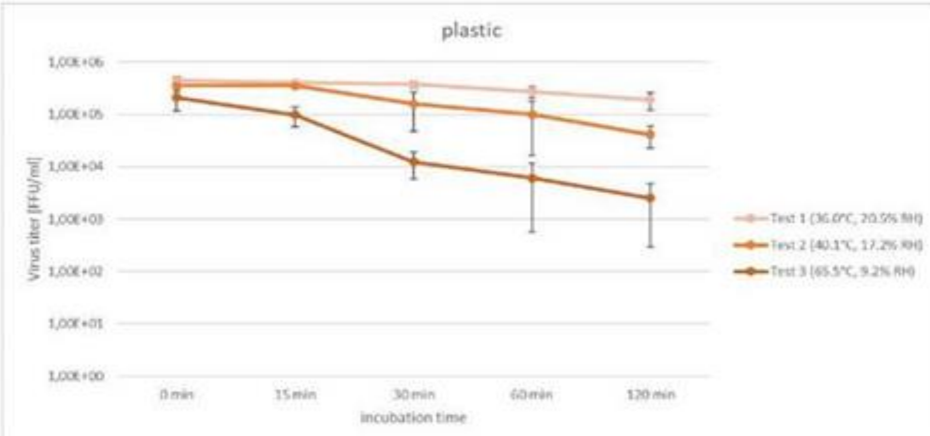

Figure 2: summarized experimental data for plastic surface after extended incubation times. The residual viral activity (FFU / ml) was determined after the indicated incubation times. The measurements were performed in triplicates for each time point. Each dot represents the mean value of the triplicates, standard deviation is indicated.

The initial virus titer at t = 0 min was 3.3 x 10^5 FFU / ml.

The virus titer and reductions after 120 minutes were as follows:

- Test 1 (36.0°C, 20.5 % RH): 1.9 x 10^5 FFU / ml, titer reduction: 0.25logs
- Test 2 (40.1°C, 17.2 % RH): 4.1 x 10^4 FFU / ml, titer reduction: 0.91logs
- Test 3 (65.5°C, 9.2 % RH): 2.5 x 10^3 FFU / ml, titer reduction: 2.13logs

Conclusions:

- As observed in previous experiments conducted by [redacted], the reduction of the virus titer correlated with elevated temperatures and longer incubation times.
- The observed titer reduction was higher on the smooth plastic surface (acrylic glass) than on the rough plastic surface (2.83 logs vs. 2.13 logs). This might be due to better protection of the virus in the cavities of the rough material or to different recovery rates from the surface.

1.2.2 Variation of humidity

One temperature setting of 55°C was tested. In contrast to the experimental setup in the variation of temperature experiment above, three relative humidity (RH) rates were tested: 15 %, 30 % and 45 % RH. The temperature and relative humidity measurements were recorded for each experiment using a data logger that was included in the device. The parameters were recorded each second.

Five incubation times were tested on the plastic material: 0 minutes, 15 minutes, 30 minutes, 60 minutes and 120 minutes.

The high relative humidity levels caused problems in the experimental conditions. The cooling effect of the evaporating water led to decreased temperature. Instead of 55°C, and 15%, 30% and 45% RH, the following conditions were observed:

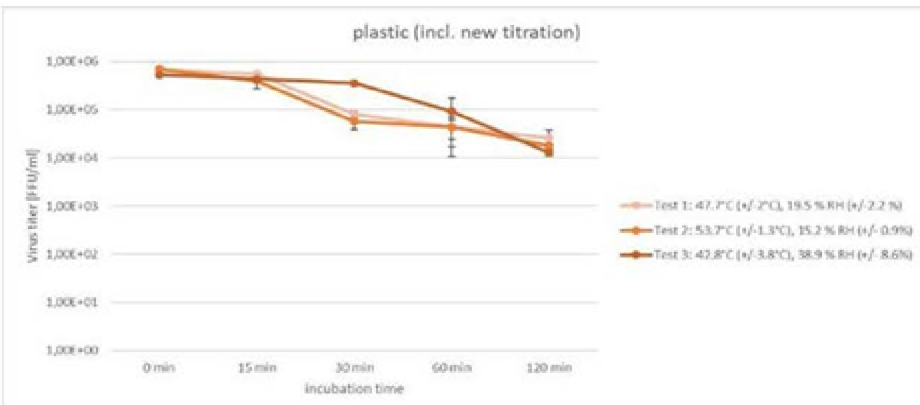

Figure 3: summarized experimental data for two different plastic surfaces (smooth surface and rough surface) after extended incubation times. The residual viral activity (FFU / ml) was determined after the indicated incubation times. The measurements were performed in triplicates for each time point. Each dot represents the mean value of the triplicates, the standard deviation is indicated.

The initial virus titer at t = 0 min was 6.3×10^5 FFU / ml

The calculated virus titers and reductions after 120 minutes were as follows:

- Test 1 (47.7°C (+/-2°C), 19.5 % RH (+/-2.2 %)): 2.6×10^4 FFU / ml, titer reduction: 1.39 logs
- Test 2 (53.7°C (+/-1.3°C), 15.2 % RH (+/- 0.9%)): 1.8×10^4 FFU / ml, titer reduction: 1.55 logs
- Test 3 (42.8°C (+/-3.8°C), 38.9 % RH (+/- 8.6%)): 1.3×10^4 FFU / ml, titer reduction: 1.69 logs

Conclusions:

The reduction of the virus titer correlated with higher temperature and higher relative humidity. Either high temperatures (65°C) or high relative humidity (~30%) lead to a higher reduction of virus titers (2.1 and 1.7 logs, respectively) after 120 minutes.

1.3 Results for virus surrogate experiments with all disinfection methods

The surrogate virus was tested under field conditions. The field test took place from the 16th-19th November 2020 at the [redacted]. An aircraft-cabin-dummy (cabin 0) was used for the experiments. The cabin 0 was not pressurized. For the termal tests the ventilation system was running to have comparable conditions to normal flight in terms of temperature and relative humidity. For testing the other disinfection system the ventilation system was off.

Figure 4: Application of the test methods in cabin 0 [redacted] and resp. the Mockup [redacted]

The experimental procedure was comparable to the laboratory setting. The virus solution (20 µl) was pipetted on sterilized 2 x 2 cm pieces of tray table material (the same material as used for the laboratory experiments above). After the disinfection procedures, the virus was then recovered by suspending the residual or dried virus with cell culture medium. The titration experiments were perfomed at [redacted].

The following positions in cabin 0 were chosen for placing the samples:

<u>Position</u>

1	**Lav A Flush button**
2	**Galley 1 middle of working area**
3	**Seat Row 1 RH Outboard seat buckle**
4A	**Seat Row 2 RH Outboard table topside**
4B	**Seat Row 2 RH Outboard table underside**
5	**Seat Row 4 LH Window Shade handle open**
6	**Seat Row 7 RH Aisle armrest**
7	**Cockpit RH Sidestick**
8	**LH3 Bin open inside handle**
9	**Seat row 5 LH Armrest between B and C lift up underside**
10	**Lav A Door handle outside**

The following disinfection procedures were performed:

Test #	Test date	Test ID	Test description
Test I	16.11.2020	Thermal humid 1	Thermal disinfection, 55°C, RH 11%
Test II	17.11.2020	UVC	Disinfection with UV-C radiation at 254nm
Test III	17.11.2020	Thermal dry overnight simulation	Thermal disinfection overnight, 40°C, RH 17%
Test IV	18.11.2020	Liquid 1	Disinfection with fogging of liquid NetBiokem
Test V	18.11.2020	Liquid 2	Disinfection with electrostatic spraying of liquid Calla1452
Test VI	18.11.2020	Thermal humid 2	Thermal disinfection, 46°C, RH 20%
Test VII	19.11.2020	H2O2 TLD	Disinfection of gaseous H2O2, 0.04ppm
Test VIII	19.11.2020	H2O2 Cleamix	Disinfection of gaseous H2O2, 100ppm

The virus titer of the virus solution was 1,42 x 10^8 TCID50/ml. Each position was tested in triplicates. Control samples were incubated outside of the cabin at room temperature and were not exposed to any disinfection procedure. Control samples were prepared on a daily basis.
The viral titers were calculated as 50% endpoint per ml (TCID50 /ml) using serial dilutions based on Reed & Muench (2). In order to calculate the reduction of the virus titer for each disinfection procedure, the mean value of all control samples was used. Control samples which showed no titer were excluded from analysis. Disinfection procedures that resulted in a titer of 0 were set to 10 for calculating the log reduction.

		Mean TCID50/ml	SD	
	Daily controls:	5,79E+05	1,00E+06	
Test #	**Test ID**	**log reduction**	**SD**	**Reduction %**
Test I	Thermal humid 1	-0,93	0,69	88,274
Test II	UVC	-1,81	1,72	98,463
Test III	Thermal dry; overnight simulation	-0,56	0,29	72,621
Test IV	Liquid 1	-2,23	0,34	99,409
Test V	Liquid 2	-1,18	1,31	93,317
Test VI	Thermal humid 2	-2,37	0,46	99,575
Test VII	H2O2_TLD	-1,26	0,36	94,503
Test VIII	H2O2_Cleamix	-4,76	0,00	99,998

Table 1: Determined titer reductions for PRRSV (Porcine Respiratory and Reproductive Syndrome Virus) after different disinfection procedures. The different disinfection procedures with the corresponding dates are indicated. The mean of the virus titers of the different tested positions ($TCID_{50}$ / ml) was determined and the log reduction with standard deviation was calculated compared to the mean value of the daily controls. The % reduction was calculated based on the log reduction.

Conclusions:

- The individual control samples showed very inconsistent titers (ranging from 0 to 3.2 x 10^6 TCID50 /ml) which are substantially lower than the initial titration experiment before the transport. Therefore, suboptimal conditions during the handling procedure or the transport to Leipzig cannot be excluded. The mean of all control samples may be used for the analysis to reduce the impact of outliers in the daily values. The mean value of the four control samples is 5.79 x 10^5 TCID50/ml. Control samples which showed no titer were excluded from analysis.
- All disinfection procedures led to a reduction of the virus titer.
- The lowest reduction was achieved in Test III (Thermal dry, overnight simulation) with 72.62% reduction.
- The test procedures that resulted in a disinfection of at least 99% were Test IV (Liquid 1) with 99.409 % reduction, Test VI (Thermal humid 2) with 99.575% reduction and test VIII (H2O2), with 99.998% reduction.
- Interestingly test VII which used the same disinfectant as Test VIII (H2O2), only led to a reduction of 1.06 logs (94.50%) of the virus titer compared to the control samples.

1.4 Results discussion

The data obtained from the conducted experiments with SARS-CoV-2 support previous results described in literature.

Doremalen et al. (1) showed that SARS-CoV-2 was more stable on plastic and stainless steel than on copper and cardboard, and viable virus could be detected up to 72 hours after application to these surfaces.

Riddel et al. (2) demonstrated that infectious SARS-CoV-2 can be recovered from nonporous surfaces for at least 28 days at ambient temperature and humidity (20 °C and 50% RH). They further demonstrated that increasing temperatures together with higher humidity rates reduced the survivability of the virus to 24 h at 40 °C.

Another study from Ben-Shmuel et al. (3) observed that SARS-CoV-2 gradually lost its infectivity completely by day 4 at room temperature under laboratory-controlled conditions, and that the decrease of infectivity on surfaces directly correlated with an increase in temperature. Although the virus titer used in these experiments was high, according to Riddel et al. it represents a plausible amount of virus that may be deposited on a surface (2).

In the present study, the experimental setup was designed to mimic droplets of infected persons, spread by coughing, sneezing or speaking. With longer incubation times and lower relative humidities, the virus completely dried on the surface. This is a major difference compared to other studies, where only one state (either liquid or dried) was investigated. This transition from a liquid to a dry state seems to increase the stability of the virus. For the higher temperatures, the highest loss in viral activity was observed between 0 minutes to 30 minutes. In the following timepoints the viral activity decreased slower.

The surface and the composition of the sample material where the virus is applied on have a great impact on the residual virus activity as well. This might be due to the thermal conductivity of the material (metal versus plastic) but also to the surface itself (smooth versus rough surface).

Both parameters are important for the transition from a liquid to a dry state and for the following ability to recover the virus from the surface.

As a surrogate for SARS-CoV-2 the *Porcine Respiratory and Reproductive Syndrome Virus* was used. It is an enveloped, positive strand single stranded RNA virus and causes respiratory infections in pigs. Since SARS-CoV-2 can only be handled in an BSL-3 laboratory, an attenuated vaccine strain of PRRSV (porcilis) was used for testing disinfection procedures at [redacted] in an aircraft-dummy cabin. The experiments under laboratory conditions yielded comparable results as for SARS-CoV-2. Therefore, the suggested PRRSV strain seems to be a suitable surrogate virus for SARS-CoV-2.
The results of the field testing showed different efficiencies for the tested disinfection procedures. The highest efficiency was achieved by treatment with gaseous H_2O_2 (99.998%), a widely used disinfection procedure, while the other procedures were less efficient. All test procedures showed a reduction of the virus titers compared to the control samples. The observed reduction was comparable to the results of the previous lab tests with PRRSV and SARS-CoV-2.

2. Aircraft material compatibility of disinfection methods

2.1 Thermal disinfection

2.1.1. Material compatibility

For equipment, the long-term temperature effects can be considered as partially covered by component qualification. While most equipment outside the cabin are qualified for long term operation up to 70°C, equipment installed in a temperature controlled environment such as the cabin is typically only qualified for operation up to 55°C. However, it can be considered that all equipment have been qualified for non-operation (depowered) up to 85°C, thus it is recommended to conduct a thermal disinfection process while the aircraft is depowered. Although aging effects on materials due to repetitive warming cannot be fully excluded. Thermal treatment to 55°C or 65°C can be considered, as it is very similar to Aircraft parked in hot environments during which very similar, even higher temperatures can be expected. As a conclusion, the A/C can be considered compatible with thermal disinfection, provided specific items are removed, as they are known to be sensitive against overheating.

2.1.2. Short and long term effects (Corrosion, visual effects, bleaching, embrittlement, hardening, impact on equipment)

For equipment and aircraft parts, the long-term temperature effects can be considered as partially covered by component qualification (metal as well as plastic etc.). Final status has not been fully assessed. Especially aesthetical aspects of decorative materials have not been assessed yet.

2.2 Disinfection with UV-C

2.2.1. Material compatibility

Ultraviolet light causes photochemical effects within polymeric materials that lead to visible and invisible degradation. Especially UV-C has enough energy to break up chemical bonds which leads to chain scission.

Fabrics used in aircraft interiors consist at least partly of polymeric materials which is why their damage under the influence of UV-C is comparable to hard materials. Degradation linked to UV can be visible in the following phenomena:

- discoloration, especially yellowing or whitening ('chalking')
- embrittlement of the surface
- loss of mechanical strength
- visible blinding and micro-cracks in transparencies

Due to the particular properties of UV-C radiation, defects will most likely not extend deeper than 0.5 mm into the component.

Figure 5

Example of heavy discoloration (Decorative foil, left: irradiated, right: new)

2.2.2 Discussion of the fire testing results

With the exception of leather, no significant decrease of the fire properties have been observed. The average burn length and after flame time have only slightly increased or, in most cases, even decreased after irradiation. All values, except the after flame time for leather, are below the requirements of the applicable material specification and/or §25.853.

The results for smoke density and smoke gas components cannot be compared as easily as the results for flammability. For the materials that are qualified – coating, decor foil and the thermoplastics – comparisons with qualification tests can be made. Those results show that variations as seen when the values before and after irradiation are compared also appear when virgin batches are tested for qualification.

Hence, as all results are well below the requirements of the relevant material specification and/or ABD0031, the results for smoke and toxicity testing cause no concern. Heat release has not been affected negatively. There has been an increase in peak heat release for decor foil – from 26 to 30 kW/m2 – but this increase is within the deviation expected from this test method. Hence, also here, the results are no reason for concern.

Natural leather has seen an increase of 30 % in burn length. Few historical data is available at [redacted], and test reports have shown that the burn length and after flame time of natural leather are usually around 10mm and 3 – 5s respectively. Hence, given the high values for the reference sample, it cannot be excluded that the sample itself is faulty. Therefore, it would be speculative to link the increase in burn length to the effect of the radiation. The after flame time has not changed between reference and irradiated sample-. However, it is well above the requirement of ABD0031, issue F.

It can be concluded that a change in colour will appear before there will be an impact on the fire properties of cabin materials.

2.2.3. Discussion on mechanical properties

The test results show that a dose of 1 MJ/m2 has influences on cabin materials.

Figure 6

Coating before (left) and after (right) irradation.

- The adhesion of interior coating has not been affected by UV-C. This is consistentwith the unaffected appearance of the coating. Decor foil sees a massive drop in adhesion after irradiation with UV-C. Polyvinylfluoride, the polymer decor foil is based on, experiences chain scissions when exposed to ultraviolet radiation. This can lead to the failure patterns observed here. Tensile testing on decor foil could help to validate this assumption. The Figure 7 below shows that parts of the décor foil have been peeled off with the foil delamination.

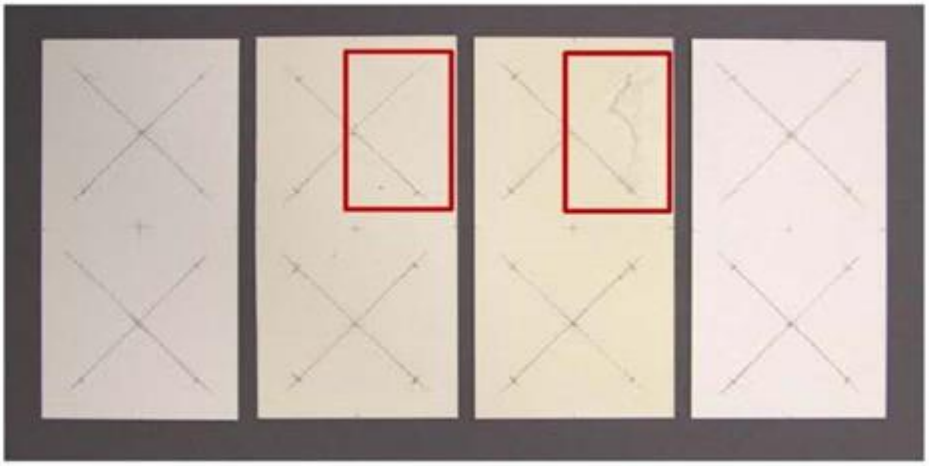

Figure 7

Adhesion testing on décor foil. Peeled off areas indicated in red. The outermost samples have not been exposed to UV-C [3]

The substrate is not visible which means that the inner adhesion of the decor foil – or the top layer itself – have been affected.

The appearance of the decor foil has been affected. The samples yellowed under the influence of UV-C. Additional exposure cycles could help to understand whether the onset of the discolouration is consistent with the onset of the mechanical degradation.

Thermoplastic materials have not been affected in their basic mechanical properties. Tensile testing has shown that no significant change occurred due to the radiation. However, their appearance has changed (see below Picture – Figure 8).

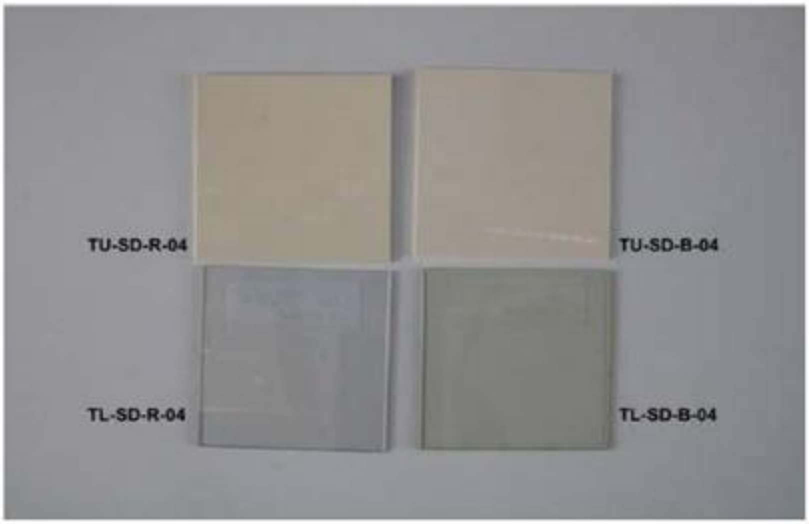

Figure 8

PC (TL) and PEI (TU) before (left) and after (right) irradation

Textiles have lost some of their tear resistance after being irradiated. The figure 9 below shows exemplarily that some samples have ruptured parallel to the tear direction before reaching the predetermined end of the test. Their tear resistance has been only half of the other sample's tear resistance and has thus not been taken into account. This behaviour has been observed on light textiles, dark textiles and for all samples made from artificial leather.

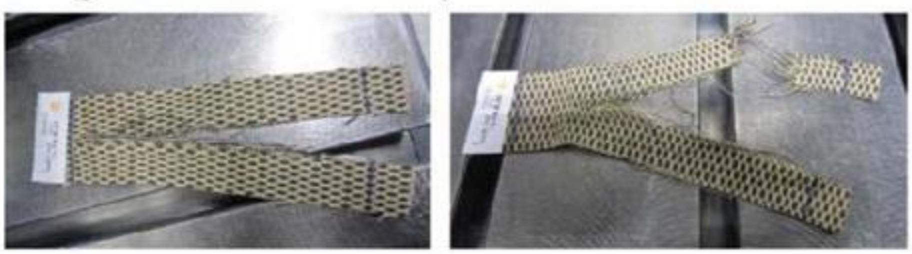

Figure 9

Textile samples failed prematurely

The valid textile samples have seen a drop in tear resistance of 31 % (light) and 17 % (dark) respectively while artificial leather has seen an increase in tear resistance. There has been a shift in colour for the textiles. Hence, as for decor foils, it has to be investigated whether this might be an indicator for acceptable levels of radiation or not.

Seat belt fabrics have also seen a slight drop in tear resistance. However, the initial tear has been applied in a warp direction. Such a damage is in the same direction of the main load application for seat belts rendering the obtained values not relevant for the actual application on board.

Additionally, instead of tearing the fibres apart, the fibres have been torn out of the textiles which means that results are invalid according to the test method applied. It is recommended to perform a test more suited to actual application and material.

The appearance of leather has not been affected by UV-C.

2.2.4. Summary for UV-C disinfection.

The test results have shown UV-C affects some cabin materials. A radiation dose of 1 MJ/m2 (which corresponds to approx 14 years of daily disinfection" (average 200J/m² per run)) does not have a significant impact on flammability, smoke density, smoke toxicity and heat release properties of cabin materials, but does have a significant impact on the adhesion of decor foils and tear resistance of interior textiles. There is also a significant impact on the appearance of thermoplastic materials, decor foils and interior textiles.

From a material point of view it remains interesting to investigate whether the onset of the change in appearance is consistent with the change of mechanical properties. Internal tests in Cabin mock-ups have shown that it cannot be sufficiently controlled when a certain dose is reached. Hence, it cannot be concluded with certainty that the colour change is a good indicator.

As there is almost no reflection of UV-C radiation, there is no diffuse irradiation at all. Continuously shadowed areas will therefore not discolor, which probably will generate an uneven color and an undesired appearance of the interior.

2.3 Disinfection with liquid

2.3.1. General considerations

Two main processes of surface disinfection with liquids can be defined:

-The first process is "conventional direct manual spraying, where applicable, and wiping to avoid fluid ingress into system parts". This is a widely accepted process, described in [redacted]. A variety of effective products against SARS-CoV-2 do exist and those who comply with AMS1452 and or AMS 1453 can be applied. The key recommendation for this process is to preferably use preimpregnated wet wipes to keep disinfecting agents localized, especially when applied frequently.

-Another process can be defined as "large area spraying / fogging" possibly combined with additional local wiping of selected surfaces on demand. Here, wetting is realized by spraying or fogging - both conventional and electrostatic – to get disinfectants to areas that might be difficult to reach otherwise. Today [redacted] does not see (electrostatic) spraying / fogging nor large area spraying / fogging as appropriate for aircraft disinfection due to potential drawbacks / concerns vs. benefits.

It is not deemed necessary for the intended disinfection efficiency and it is expected to cause negative mid and long term effects on sensitive surfaces and hidden areas of the A/C. The efficacy tests with surrogate viruses showed only a moderate log-reduction of 1 log10 (90%) - 2 log10 (99%) dependent of the method (electrostatic) spraying or (electrostatic) fogging and disinfectant used.

2.3.2 Material compatibility (Stress, FST behavior, heat release, etc.)

Material compatibility & corrosion: The ingress of liquids into hidden areas was assessed during a test and could be confirmed: in hidden areas, UV-traces of fluorescent leak finder could be found with UV-flashlight. The investigation took place one day after the test day. Traces of fluorescent leak finder were found on the insulation of underlying structure. It is safe to say that liquid disinfecting agents can enter hidden aircraft areas. A controlled spraying action with the method of electrostatic spraying or electrostatic fogging cannot ensure that the sprayed disinfectant does enter those areas. Large area spraying may also allow disinfectant to accumulate in hidden aircraft areas. Therefore, short, mid and long-term effects regarding material compatibility of fogging / spraying agents on surfaces and items (mainly hidden areas left unwiped) have to be taken into account. Corrosion in particular cannot be excluded when using these methods.

Advise caution in areas that cannot be wiped off after application of disinfecting agents: The applied agents may cause immediate negative effects (e.g. change of surface appearance or haptics) as well as more critical long-term negative effects mainly due to accumulation of critical residuals over time (e.g. corrosion and/or changing the FST (Fire Smoke and Toxicity) characteristics of the materials over time).

Disinfectant has not to be sprayed directly onto soft materials and cockpit panels. Uncontrolled spraying on soft materials has a potential impact on their flammability properties and may generate color fading. Efforts should be made to ensure the materials do not come into contact with aircraft structure. Indeed, droplets may cause potential acceleration of corrosion on aircraft structures such as seat tracks.

Moreover, please note that uncontrolled spraying on cockpit panels may generate damages on avionics and electrical equipment and cracking in some plastic items. Furthermore, ingress of disinfecting liquids into electronic equipment can lead to short term failures (i.e. current leakage and/or shortages) between adjacent conductors on electronic boards, such as contacts of connectors or components (not protected by conformal coating) by creating conductive paths that could lead to bridging contacts. Ingredients of disinfecting liquids can also lead to long term failures (i.e. current leakage and/or shortages): once penetrated into electronic equipment, chemical residuals can lead to corrosion and/or chemical migration within connectors and/or components contacts on electronic boards.

2.4 Disinfection with gaseous H2O2

2.4.1. Safety Impact and Material Compatibility (Stress, FST behaviour, heat release, etc.)

Dependent on the H2O2 concentration, humidity and temperature, hydrogen peroxide and water will condense on surfaces once the dew point is reached. Dependent on the concentration of the generated aqueous solution, corrosion of materials may occur with similar effects as for dry hydrogen peroxide. Decomposition of hydrogen peroxide will also occur in parallel and will reduce the corrosive properties.

Based on a report from the FAA it can be derived that at relatively low concentrations and exposure times an effectiveness of 99 % can be achieved (at around 10 ppm H2O2 within approx. 2.5 minutes). Available literature from the FAA indicates also that vaporized hydrogen peroxide may not have significant effects on aircraft electrical equipment and aircraft structural materials, but on mechanical properties and flammability of aviation textiles such as wool, polyester, leather and Nylon.

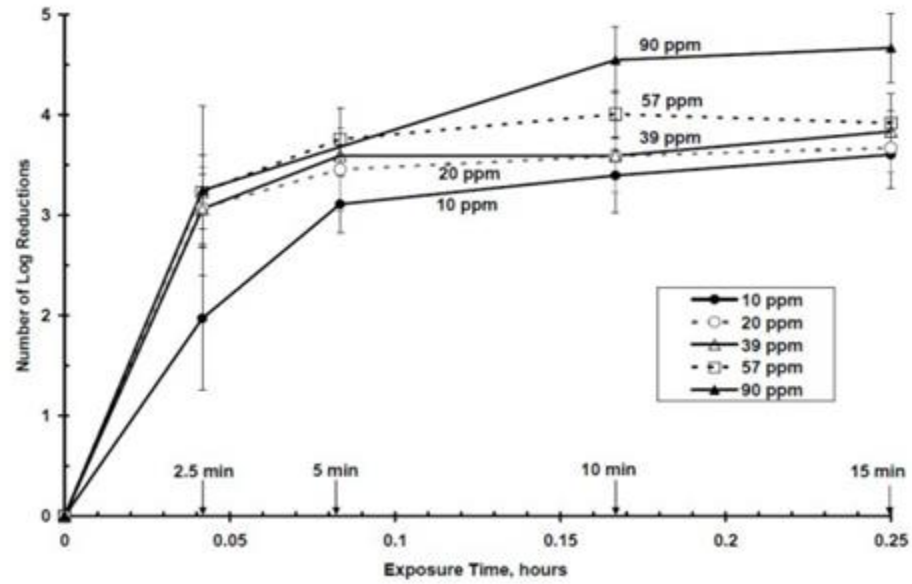

Figure 10

Surface decontamination of influenza viruses with hydrogen peroxide vapor (source: FAA).

For further details see further FAA references (§3 – Litterature):

More detailed and systematic investigations would be required on the physics of hydrogen peroxide (dew point and condensation behavior) as well as material compatibility in cooperation with dedicated material experts covering all aspects from cabin interior to aircraft structure. It may occur that generally oxidizing agents are not to be applied in aircraft, but it finally may depend on the concentration level, exposure time and number of repetitions.

Please refer also to the attached Hydrogen Peroxide Material Compatibility Chart from ISM and IS Med Specialties. https://www.industrialspec.com/images/files/hydrogen-peroxide-material-compatibility-chart-from-is m.pd

2.4.2. Short and Long Term Effects

A number of cabin materials, such as carpets and wet floor plastics, curtain textiles, decor foils, lavatory sink materials, a Polycarbonate window screen, golden chromated aluminum and an A380 cabin pressure controller has been subjected to vaporized H_2O_2 to identify materials degradation as a consequence of contact with this substance. All materials have been subjected to an H_2O_2 atmosphere of 100ppm over a period of 300h. The controller and the chromated aluminum chassis have been subjected additionally to 700ppm over 10 min.

As a summary, except for the dark blue 100% Nylon and the light blue 80% Nylon/20% wool carpets, there was no visible degradation. As Nylon is a brand name for Polyamide, which is a commonly used synthetic material, further treatment tests have been started at [redacted] to confirm, if the effect has been caused by the continuous and long term application of H_2O_2 and consequently high absorption into the fibers and if this would not happen with ventilation phases in between treatment steps giving the H_2O_2 the chance to desorb from the fibers again.

Figure 11

Different Cabin Materials before and after the treatment with 100ppm VHP over 300h

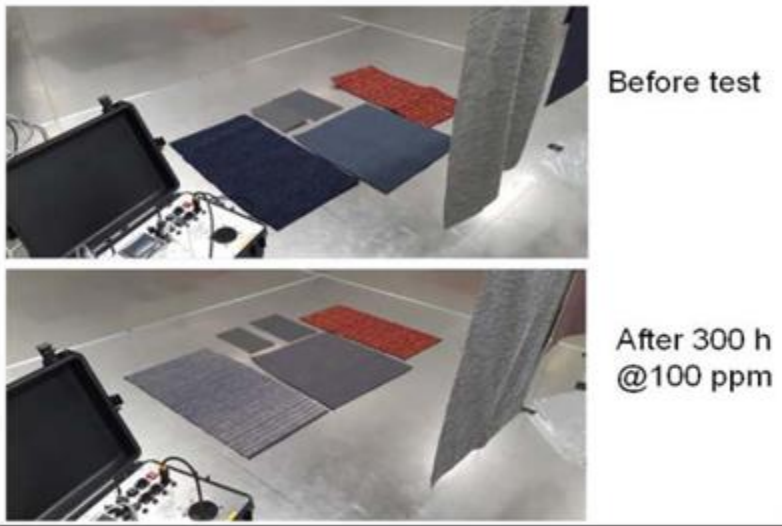

Figure 12

Different Nylon Carpet blends before and after the treatment with 100ppm VHP over 300h

An A380 Outflow Valve Control Module was tested and visually inspected after the test with no findings. The controller showed full performance and the visual inspection did not show signs of corrosion or other deterioration.

Some materials (3 wool/Nylon blend carpets, 2 textiles and 2 NTF materials) have been tested for their flammability properties in the fire lab in [redacted]. The wool/Nylon blend carpet and both fabrics failed the burn length and the after flame time test. Detailed test results are shown in the appendix 45.2. To confirm that the flammability protection was not impaired also by the continuous H2O2 subjection during the long test treatment, a retest is to be setup at Cleamix with subsequent check of the flammability characteristics.

3. Literature

1. Effect of temperature and relative humidity on the stability of infectious porcine reproductive and respiratory syndrome virus in aerosols. Hermann, J. 2007, Vet. Res.

2. A simple method of estimating fifty per cent endpoints. Am J Hyg. . Reed LJ, Muench H. 1938, Bde. ;27:493–497.

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6. Evaluation of the Effects of Hydrogen Peroxide on Common Aircraft Electrical Materials, FAA, report number DOT/FAA/AM-10/5, Office of Aerospace Medicine, Washington, DC 20591, March 2010

7.Evaluation of the Effects of Hydrogen Peroxide on Common Aviation Structural Materials, FAA, report number DOT/FAA/AM-09/23, Office of Aerospace Medicine,Washington, DC 20591, December 2009.

8. Effects of Hydrogen Peroxide on Common Aviation Textiles, FAA, report number DOT/FAA/AM-09/16, Office of Aerospace Medicine, Washington, DC 20591, August 2009

4. Appendix - Summary tables for disinfection results

Table 2 -Test results from Mockup and Lab for disinfection methods with a virus surrogate[1]

Type of Disinfection		Mean log reduction	Material compatibility		
			Fire / smoke	Visual	Tensile strength / corrosion
Thermal	55°C, 11% RH, XXmins	<1log	No effect	No effect	No effect
	40°C, 17% RH, overnight	<1log			
	46°C, 20% RH, 270mins	2.37 log			
Fogging	NetBiokem	2.23 log	Significant change of performance for soft goods	Degradation of visual appearance	Significant change of performance for soft goods
Electro-static spraying	Calla1452	1.18 log	Significant change of performance for soft goods	Degradation of visual appearance expected	Significant change of performance for soft goods
UV-C radiation	254nm	2.06 log	No significant impact observed	Discoloration	Significant degradation of adhesion of décor foils and tear resistance of interior textiles
H2O2 gaseous	0.04ppm	1.26 log	No effect	No effect	No effect
	100ppm	>4.68 log	No significant impact expected, but some flammability tests failed. Further investigation undergoing.	Discoloration	unknown

[1] The virus surrogate used: an attenuated Porcine reproductive & respiratory syndrome virus (PRRSV)

Table 3: Test results from UV-C disinfection methods

Cabin	Cockpit	Material Type	Airbus specification	Application	Colour impact	Mechanical impact	FST impact	Remarks
X	X	**PU-Coatings**	AIMS04-08-002 on Al-substrate	Decorative surfaces, e.g. CHSC	None	None	None	all specimens have been exposed to $1\ MJ/m^2$ @ 254nm
X		**PVF-based Decorative Foils**	AIMS04-09-001 on Al-substrate	Decorative surfaces, e.g. sidewalls	Yellowing	Foil disintegrated during peel-off	None	
X	X	**Polyetherimide**	AIMS04-01-001	Heat release compliant thermoplastic parts, e.g. passenger service unit (PSU)	Yellowing	None	None	
X	X	**Polycarbonate**	AIMS04-01-002	Transparencies	Yellowing	None	None	
X	X	**Textiles - Wool / Polyamide mix**	-	Curtains, Flightdeck seats	Slight colour shift	Loss of tear resistance	None	
X	X	**Textiles - Seat Belt Fabric Polyester**	-	Seat belts	None	Loss of tear resistance	None	
X	X	**Artificial Leather**	-	Seats	None	Increase of tear resistance	None	
X	X	**Leather**	-	Seats	None	N/A	significant increse in burn length	
X	X	**Carpet**	-	Cockpit floor	Yellowing depending on the material composition	N/A	N/A	

Table 4: Results from Mockup and Airplane test against Lab Sars CoV2 (liquid disinfection, H2O2 and thermal disinfection)

	[redacted]							
	PRRSV				n.a.	n.a.		
Treatment	Notes (Surfaces / Kill Time)		Reduction n (Log10)	Reduction [%]		Aircraft Material Compatibility		
Electrostatic Spray-Calla 1452								
device: MaxCharge ESS SC-EB; cabin: empty; airflow: off; OHSC: open (partly); temp: 24 °C; 386 ml (3% dilution); environment: fwd. section A320 test bench with 8 rows, 1 lav. & 1 galley	[illegible]	1,18	1,31	93,39%		significant change of performance for soft goods (dependent on disinfectant)	degradation of visual appearance to be expected (dependent on disinfectant)	significant change of performance for soft goods (dependent on disinfectant); corrosion in electrical equipment cannot be excluded when using this method
Application possible in Single Aisle A/C in < 20 min with 2 Operators								
Electrostatic Fogging-Bacticlean								
device: HurricaNovaES; cabin: empty; airflow: off; OHSC: open (partly); temp: 25 °C; 180 ml (RTU) used; environment: fwd. section A320 test bench with 8 rows, 1 lav. & 1 galley.	[illegible]	2,23	0,34	99,41%		significant change of performance for soft goods (dependent on disinfectant)	degradation of visual appearance to be expected (dependent on disinfectant)	significant change of performance for soft goods (dependent on disinfectant); corrosion in electrical equipment cannot be excluded when using this method
Application possible in Single Aisle A/C in < 20 min with 2 Operators								
H2O2: Gaseous Hydrogen Peroxide								
0.04ppm after 1 h	[illegible]	1,26	0,86	94,50%		no known effect	no known effect	no known effect
100 ppm - 40 min dwell time plus increase and decrease time. Decrease time was > 60 min until concentration was below 1 ppm	[illegible]	4,68	0,00	99,99%		Degradation of performance after exposure for 300h	Severe discoloration after exposure for 300h	unknown
Thermal Disinfection								
Thermal 45°C RH 11% (240 min)	[illegible]	0,93	0,69	88,25%		no effect	no effect	no effect
Thermal 40°C RH 17% (overnight 7h: heat up, doors closed & heating stoped)	[illegible]	0,56	0,29	72,45%		no effect	no effect	no effect
Thermal 46°C RH 20% (270 min)	[illegible]	2,37	0,46	99,57%		no effect	no effect	no effect
Thermal 40°C RH 17% 120 min	Plastic Tray table	0,91						
Thermal 65°C RH 9% 120 min	Plastic Tray table	2,13						
Thermal 43°C RH 39% 120 min	Plastic Tray table	1,49						
Thermal 54°C RH 15% 120 min	Plastic Tray table	1,55						

- 1 log10 reduction = 90% reduction
- 2 log10 reduction = 99% reduction
- 3 log10 reduction = 99.9% reduction
- 4 log10 reduction = 99.99% reduction
- 5 log10 reduction = 99.999% reduction

The surfaces tested are identified as follows:
Aa: Armrest Aisle; Al: Armrest Lift up underside; Bh: Bin inside handle; Cs: Cockpit Sidestick; Ld: Lavatory door handle; Lf: Lavatory flush button; Tt: Tray Table top side; Tu: Tray Table under side; Wh: Window Shade handle

Table 5 - Gaseous H202 - Detailed Flammability results

			as is	exposed			
Carpet			21-0086	21-0085			
	AITM 2-0002 B	Burn length [mm]	65	109	**Fail**		
		After Flame Time [s]	2,4	> 60	***beyond certification threshold***		
		After Flame Time of drips [s	0	0			
			21-0090	21-0089			
	AITM 2-0002 B	Burn length [mm]	48	42			
		After Flame Time [s]	2,3	2,7			
		After Flame Time of drips [s	0	0			
			21-0088	21-0087			
	AITM 2-0002 B	Burn length [mm]	63	49			
		After Flame Time [s]	1,8	2,5			
		After Flame Time of drips [s	0	0			
				21-0083			
NTF	AITM 2-0002 B	Burn length [mm]	35	44	**Fail**		
		After Flame Time [s]	0	0			
		After Flame Time of drips [s	0	0			
			21-0082	21-0081			
	AITM 2-0002 B	Burn length [mm]	23	21			
		After Flame Time [s]	0	0			
		After Flame Time of drips [s	0	0			
			21-0094	21-0093			
Textile			117	204	***beyond certification threshold***		
			7,1	18,8	***beyond certification threshold***		
			0	0			
			21-0092	21-0091			
			21	123	**Fail**		
			0	0			
			0	0			

F Original equipment manufacturer 6 documents

[redacted]

Technical Engineering Report

DOCUMENT NO.: **RPT-57-0001**

REV: **B**

TITLE: **Aircraft Material Compatability to 254nm Ultraviolet-C (UVC) Light**

THIS REPORT IS APPLICABLE TO THE FOLLOWING [redacted] AIRCRAFT MODEL(S):

[redacted]	[redacted]	[redacted]	[redacted]

ATA REFERENCES			

ECCN = Export Control Classification Number

FOR DISCLOSURE TO THE AIRWORTHINESS AUTHORITIES

DT4067 -B

[redacted]

DISTRIBUTION LIST

PAGE: ii
DATE: 2021-09-27

REPORT NUMBER:	**RPT-57-0001**	REVISION:	**B**
REPORT TITLE:	**AIRCRAFT M ATERIAL COM PATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT**		

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[redacted]	[redacted]	

[redacted]

SUMMARY

CAGE CODE 71867

DOCUMENT NUMBER:	**RPT-57-0001**	REVISION:	**B**
TITLE:	**AIRCRAFT MATERIAL COMPATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT**		
AUTHOR:	[redacted]		
THIS SUMMARY IS APPLICABLE TO THE FOLLOWING MODEL(S):			
[redacted]	[redacted]	[redacted]	[redacted]

A series of tests were conducted to determine the impact of 254nm ultraviolet-c (UVC) light on various aircraft materials. The tests assessed the impact of UVC exposure on tensile strength, stress cracking, flammability, transmissibility, and appearance. It was found that tensile strength, flammability, stress cracking was unaffected. The evaluation for appearance was less stringent but concluded that materials exposed to an equivalent of 5000 disinfections experienced only negligible to slight discoloration (NSD). Finally, transmissibility tests concluded that UVC light at 254nm does not permeate through the window dust pane allowing windows shades to remain open during disinfection. Therefore, the work presented in this report provides the foundational data and substantiation to allow UVC disinfection in the [redacted] cabin as per AMM 12-21-00-160-801 to safeguard against current and future threats and to provide a chemical-free, effective, and sustainable disinfection scheme for the [redacted] aircraft.

Note: Contact release group for the complete document.

AIRCRAFT MATERIAL COMPATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT

INITIAL APPROVAL PAGE

This page is for [redacted] Initial Release (Revision --) sign-off only!

Further revisions shall be documented on the Revision / Approval Log page(s).

[redacted] Initial Approval

PREPARED ______________________
[redacted]

CHECKED ______________________
[redacted]

APPROVED ______________________
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AIRCRAFT MATERIAL COMPATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT

REVISION/APPROVAL LOG PAGE

Rev.	Date	Revised by	Checked by	Approved by	Approved by (if required)
--	2021-04-15	See page iv for initial approval.			
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		NIAR release copy for FAA evaluation.			
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		Added avionics panel test results			
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AIRCRAFT M ATERIAL COMPATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT

1. REFERENCES

[1] ML000135-2021 – Tensile Testing of Thermoplastic After UV Exposure

[2] ML000258-2021 – Flammability Test Data Sheets

[3] ML000449-2021 – Stress Cracking After UVC Exposure

[4] Seatbelt Pull Test Results

2. OVERVIEW

2.1 TERMS AND DEFINITIONS

Irradiance: measure of the amount of UVC light hitting a unit area in a unit time

$$i = 1\frac{mW}{cm^2}$$

Fluence: measure of the total amount of UVC energy hitting a unit area

$$F = 1\frac{mJ}{cm^2}$$

Inverse Square Law: governs the relationship between irradiance and distance

$$i \propto \frac{1}{d^2}$$

In the absence of any reflections, if the source to receiver distance is doubled, irradiance would reduce by a factor of 4.

Disinfection Dose: the amount of UVC fluence casted on a material per disinfection cycle. The autonomous robot RAY is programmed to move through the aisle at a fixed speed.

A single pass of RAY with all lamps operating (***heavy disinfection***) casts 15mJ/ cm^2 on surfaces as far away as sidewall. A single pass on RAY with half the number of lamps operating (***light disinfection***) casts 7.5mJ/ cm^2 on the sidewall. A dual pass would result in double the amount specified on materials being exposed to both passes.

NSD: author's acronym for ***negligible to slight discoloration***. The philosophy undertaken in this study is to expose each material to a very high amount of cumulative fluence in increments of ~50J/ cm^2. The goal was to determine an increment after which negligible to slight discoloration is observed for each material.

2.2 MOTIVATION FOR TEST

With the onset of the covid-19 pandemic, and with disinfection becoming a normalcy in the pandemic and post-pandemic era, UVC has gained interest in the aviation industry as a potential means of disinfecting cabin surfaces. Due to the pronounced use of thermoplastics, fabrics, and leather in aircraft cabin interiors, it is important to assess the longer-term impact on appearance, material properties, and flammability.

2.3 MATERIAL SELECTION AND TEST MATRIX

Specimen ID	Material Name		Appearance	Tensile	Stress Cracking	Flammability	Transmissibility
1	Polycarbonate	Lexan 9604	X				X
2	Polyetherimide Blend	Ultem 1668	X	X	X	X	
3	PVC/ Acrylic	Royalite R60	X	X	X	X	
4	Modified ABS	Boltaron 4330	X	X	X	X	
5	Chlorinated Polyvinyl Chloride – CPVC	Aeroform LHR	X	X	X	X	
6	Upholstery Fabric (Dark)	90% wool, 10% nylon	X				
7	Polycarbonate	Lexan FMR 604-116	X				X
8	Leather	Lantal	X			X	
10	Injection Molded Parts	Lexan FST-9705 (Window Reveal)	X				
11	Unknown	Window Shade (old interior)	X				
12	Chlorinated Polyvinyl Chloride – CPVC	Aerform (grey side)	X				
13	Upholstery Fabric (Light)	90% wool, 10% nylon	X				
14	Placard	Colored vinyl film with adhesive backing + clear polyester film over-laminate	X				
15	Polyetherimide Blend	Ultem 9075	X				
16	Decorative Laminate on Composite	Tedlar on Honeycomb Composite Panel	X			X	
17	Seat Belt	Nylon Webbing		X			
18	Avionics Display Panel		X				

3. TEST EQUIPM ENT

3.1 UVC Source

UVC light was produced using one or two amalgam lamp bulbs produced by UVC Spectrum Ltd. The length of each bulb is 1000mm with radiating length being 920mm. The UV output at 254nm is 52W with the irradiance at 1 m being 460µW/ cm^2. The frequency spectrum is shown in Figure 1. in the spatial domain as wavelength, demonstrating that the radiated energy from the UVC lamp is predominantly focused at a wavelength of254nm.

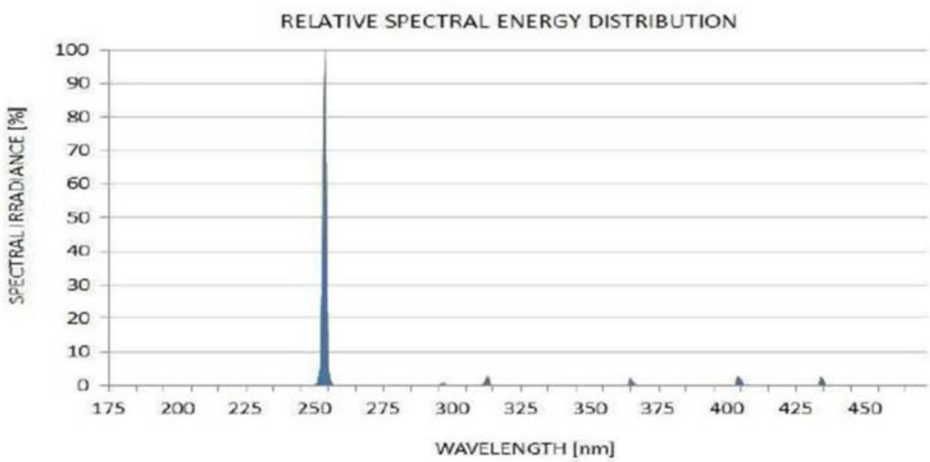


Figure 1 – Spectral irradiance indicating that energy is concentrated at 254nm wavelength.

3.2 Apparatus

The lamps were affixed to an aluminum fixture with the sides being made of aluminum to increase reflected energy on to the materials. A total of two lamps were used at a height of 34cm with options to turn off one lamp as well as to increase the height to 52cm to reduce the intensity. The latter facilitated a more accurate intensity replication onto materials that are exposed to less intensity due to their increased distance from the disinfection source. For example, sidewall and window shade.

3.3 UVC Measurement Device

The irradiance was measured in milliwatts per centimeter squared at various points near the surfaces of each material. The measured irradiance was multiplied by time (in seconds) to generate Fluence measured in millijoules (or joules) per centimeter squared. The device is produced by International Light Technologies Part Number ILT770, Serial Number XCB270 with an ISO17025, NIST traceable calibration. The unit is a broadband unit calibrated to a wavelength of 270nm. Therefore, the irradiance measured at 254nm, will need to be corrected by the response curve. More specifically, the value measured must be divided by 0.7295 to correct the reading to a wavelength of 254nm in accordance with the manufacturer's frequency response curve.

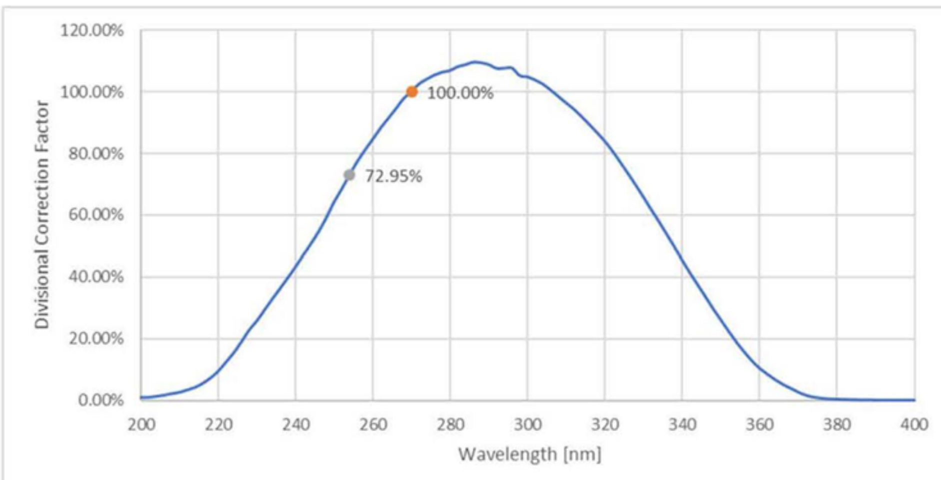


Figure 2 – Wavelength response of the measurement device. Wavelength response must be divided by shown value to calibrate to the desired irradiance. For example, if the source is emitting at a wavelength of 254nm, the measured irradiance would need to be divided by 0.7295 to correct for the actual irradiance of the source.

A secondary measurement technique was used for the transmissibility test to determine energy transmission through a material. The technique utilizes Intellego Technologies Dosimeter Cards that have a colorimetric indicator that changes color when a certain amount of fluence have been accumulated on the cards.

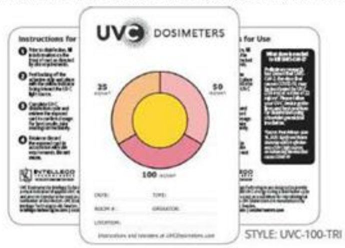


Figure 3 – The cards were used for the transmissibility test as a visible demonstrator of energy transmission through materials.

3.4 Apparatus Grid

Several grid measurements were conducted throughout the measurement campaign to determine the spatial UVC irradiance on the test bed. The measurement was conducted by roving the UVC meter receptor across the test bed. During the measurement, the UVC meter was left at a certain location to measure the reference irradiance. The reference measurement was used to ensure no drastic changes in irradiance occurred throughout the course of the measurement which in some instances lasted several days. The average irradiance over each sample was then used to determine the cumulative fluence.

4. TENSILE STRENGTH AND STRESS CRACKING TEST

4.1 TEST SETTING

The UVC exposition was conducted over three days spanning December 9, 2020 to December 11, 2020 at aero hygenx facility. The test was witnessed by [redacted] in person and via Microsoft Teams. The test was also witnessed by [redacted] authorities for familiarization purposes. The entire duration of exposition was recorded on Microsoft Teams with some data dropouts during the 49 hours of recording. This is referred to as Set 1.

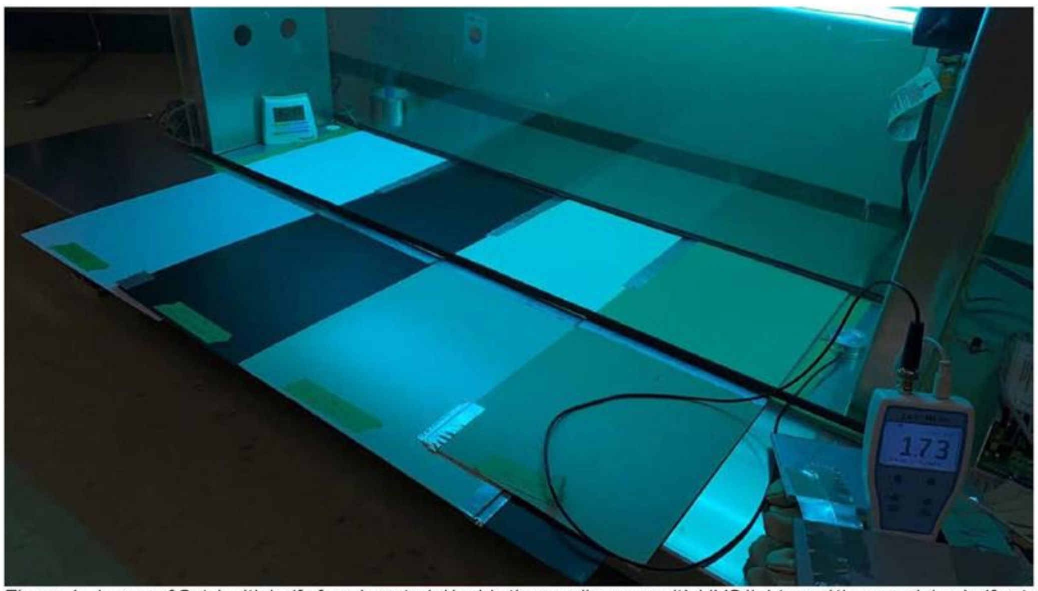


Figure 4 – Image of Set 1 with half of each material inside the acrylic cover with UVC lights and the remaining half not exposed to UVC. This image was captured on December 10, 2020 at 14:40 showing a reference reading of 1.73mW/cm². Correcting this by the 0.7295 factor results in 254nm irradiance of 2.37 mW/cm².

4.2 GRID IRRADIANCE MEASUREMENT

A grid measurement was performed to determine the spatial irradiance on the test bed. This was used to determine the fluence. A reference point indicated in red was used to monitor the irradiance throughout the exposition to ensure minimal changes in irradiance.

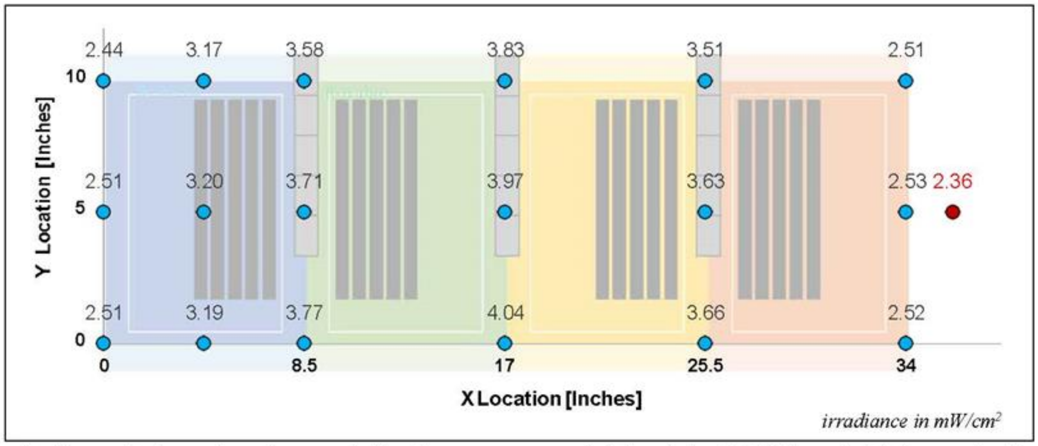


Figure 5 – The graph above shows the corrected irradiance measurements taken during **Set 1**. The material placement on the testbed is overlaid on the same graph with black strips showing the sections used for tensile coupons and grey strips showing the section used for appearance evaluation (to be covered in Section 7). Steady state values in irradiance is shown after the test chamber reached a stable temperature and humidity.

4.3 CUMULATIVE FLUENCE CALCULAT ION

The average irradiance was determined for each material and for specific region related to the test. Where irradiance measurements were not available to confine the area of the samples, a linear interpolant was used between measured spatial points. As an example, for Boltaron the 6 measured points were used to determine the average irradiance directly. However, for Royalite, the 3 measured points and 3 interpolated points were used – the interpolated points simply reducing to the average of the left and the right measured points.

The following equation was used to then calculate the cumulative fluence, F, using the irradiance, E, and total time, t:

$$F = E * t$$

During the test start, it was observed that a spike in irradiance occurs followed by a dip which stabilizes to a steady state. This is likely due to the air trapped inside the chamber warming up resulting in changes in the lamp efficiency. For simplicity and for conservatism, the lower steady state value was used for the entire duration of the exposition rather than integrating the spike which would have resulted in a slightly higher fluence values.

4.4 TENSILE TEST RESULTS

Specimens were prepared and tested as per ASTM D638 with a reduced length to 7.5" for material preservation. A total of 5 coupons were cut from the exposed section and non-exposed section of the same material. The tensile test was performed at [redacted].

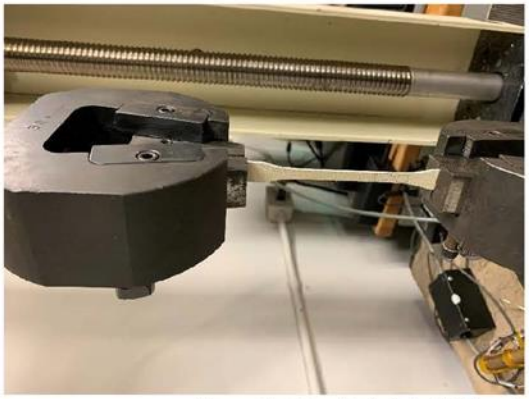


Figure 6 – Tensile test rig (left) and coupons of Ultem 1668 (right).

The average tensile strength was calculated for each batch as shown in Table 1.

Table 1 - Average irradiance and Cumulative Fluence for each material sample in the area used for tensile strength testing.

Specimen ID	Material	Irradiance $(\frac{mW}{cm^2})$	Total Time of Exposure $(seconds)$	Cumulative Fluence $(\frac{J}{cm^2})$
2	Ultem 1668	3.7 ± 0.1	177180	650 ± 20
3	Royalite R60	3.8 ± 0.1		670 ± 20
4	Boltaron 4330	3.4 ± 0.3		610 ± 50
5	Aeroform LHR	3.3 ± 0.3		590 ± 50

Table 2 – Average tensile strength of unexposed and exposed coupons.

Material		Average Tensile Strength [KSI]	
		Control, Unexposed	Test, Exposed
Boltaron 4330	Modified ABS	5.06	5.06
Aeroform LHR	Chlorinated Polyvinyl Chloride – CPVC	7.94	7.86
Ultem 1668	Polyetherimide Blend	20.0	20.3
Royalite R60	PVC/ Acrylic	5.54	5.54

Therefore, exposing thermoplastics to 590-670J/ cm^2 as shown in Table 1 has no appreciable effect on the tensile strength of the materials.

4.5 STRESS CRACKING RESULTS

Table 3 – Irradiance and Fluence for each material sample in the area used for stress cracking test.

Specimen ID	Material	Irradiance $(\frac{mW}{cm^2})$	Total Time of Exposure $(seconds)$	Cumulative Fluence $(\frac{J}{cm^2})$
2	Ultem 1668	3.9 ± 0.1	177180	680 ± 20
3	Royalite R60	3.9 ± 0.1		690 ± 20
4	Boltaron 4330	2.8 ± 0.4		500 ± 60
5	Aeroform LHR	2.8 ± 0.3		490 ± 50

The remaining areas of the same materials were used to study stress cracking as per DHLP 6043.

The results are summarized:

Table 4 – Stress cracking of thermoplastics.

Material		Stress Cracking Exposed Results
Boltaron 4330	Modified ABS	No cracking observed after 7 days under stress at room temperature.
Aeroform LHR	Chlorinated Polyvinyl Chloride – CPVC	
Ultem 1668	Polyetherimide Blend	
Royalite R60	PVC/ Acrylic	

Therefore, exposing the four types of thermoplastics to 490-690 J/cm^2 as shown in Table 3 does not result in the material exhibiting signs of cracking under stress.

5. FLAMMABILITY TEST

5.1 TEST SETTING

The UVC exposition was conducted over three days spanning January 19, 2021 to January 21, 2021 at aero hygenx facility to complete Set 3a exposition comprised of Boltaron, Aerform LHR, Ultem, and Royalite. A second session was conducted over three days spanning January 28, 2021 to February 2, 2021 to complete Set 3b comprised of leather and sidewall. The test was witnessed periodically by [redacted] via Microsoft Teams. The entire duration of exposition was recorded on Microsoft Teams with some data dropouts.

5.2 GRID IRRADIANCE MEASUREMENT

A grid measurement was performed to determine the spatial irradiance on the test bed. This was used to ultimately determine the fluence. A reference point indicated in red was used to monitor the irradiance throughout the exposition to ensure minimal changes. The samples were arranged in an alternating manner to normalize the average intensity and ensure that each material is exposed to similar cumulative Fluence on average.

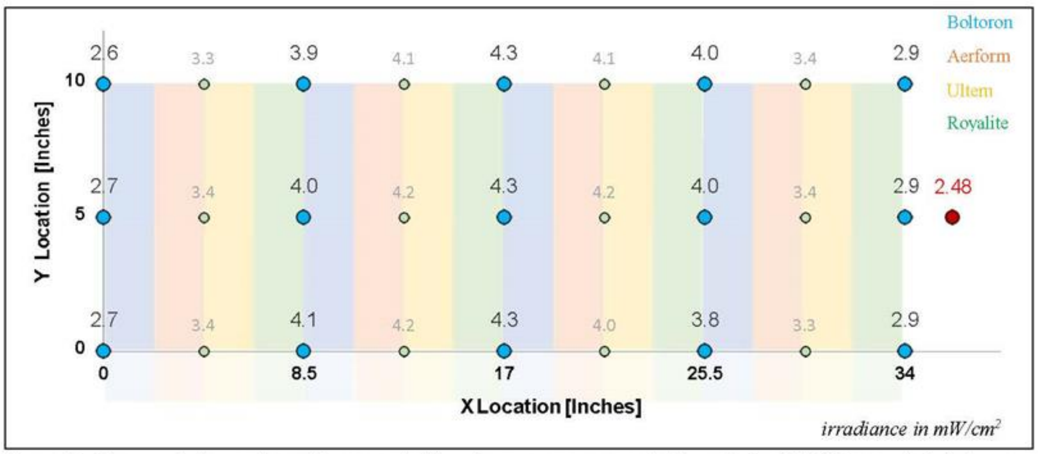


Figure 7 – The graph above shows the corrected irradiance measurements taken during Set 3. The material placement on the testbed is overlaid on the same graph to show the materials used during **Set 3a**. Measured values are shown in blue. Interpolated values are shown in green to facililate calculation. The values show the steady state values in irradiance after the test chamber was allowed to reach a stable temperature and humidity.

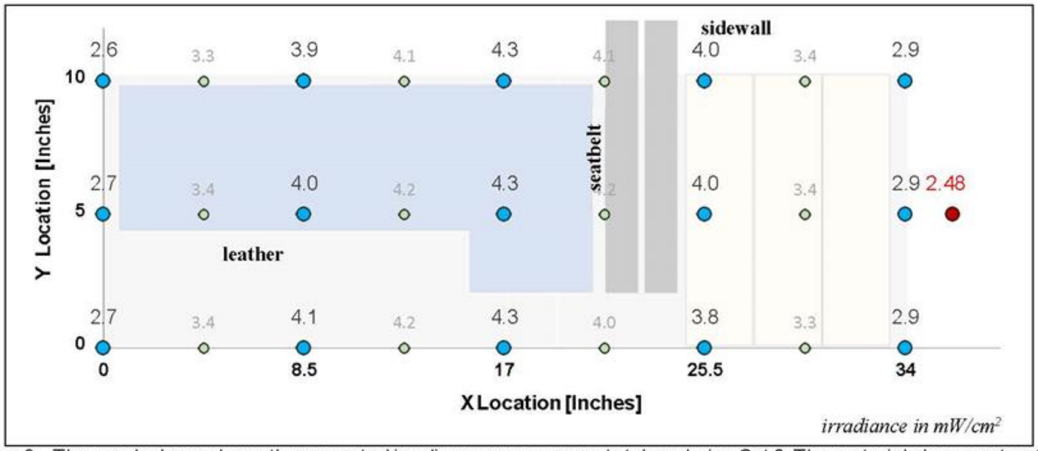


Figure 8 – The graph above shows the corrected irradiance measurements taken during Set 3. The material placement on the testbed is overlaid on the same graph to show the materials used during **Set 3b**. Measured values are shown in blue. Interpolated values are shown in green to facililate calculation. The values show the steady state values in irradiance after the test chamber was allowed to reach a stable temperature and humidity.

5.3 FLAMMABILITY RESULTS

Test was conducted as per FAR 25.853(a) Appendix F Part 1(a)1(i) and (ii).

Table 5 – Average irradiance and Cumulative Fluence for each material sample in the area used for flammability testing. Note that the leather has higher variance as it encompassed a larger area of the test bed.

Specimen ID	Material	Irradiance $(\frac{mW}{cm^2})$	Total Time of Exposure $(seconds)$	Cumulative Fluence $(\frac{J}{cm^2})$
2b	Ultem 1668	3.7 ± 0.6	171720	640 ± 90
3b	Royalite R60	3.8 ± 0.5		650 ± 80
4b	Boltaron 4330	3.8 ± 0.4		640 ± 70
5b	Aeroform LHR	3.8 ± 0.5		650 ± 80
8	Leather	3.8 ± 0.6	176700	660 ± 100
16b	Tedlar on Honeycomb Composite Panel	3.5 ± 0.4		620 ± 80

Figure 9 – Boltaron and leather was tested to test code F2 whereas all other materials tested to test code F1. The graph shows the measured extinguish time. The control (unexposed) test was not performed for Royalite, Leather, and Sidewall Panel.

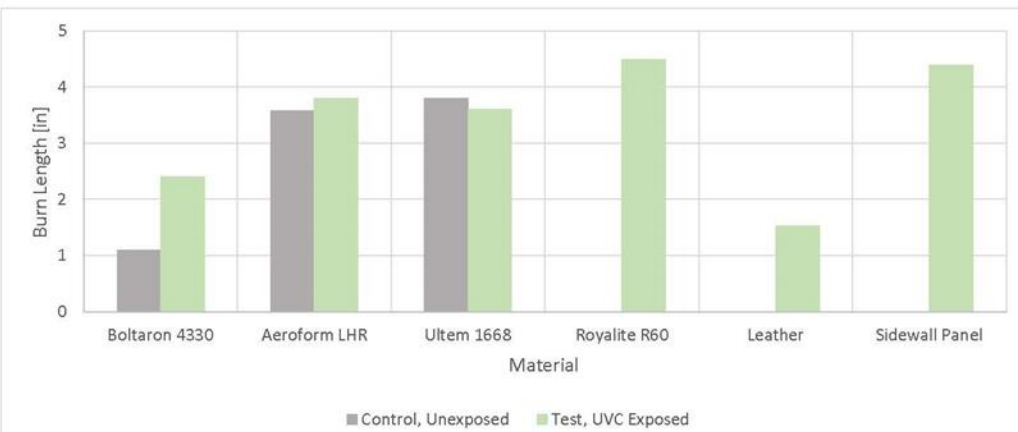


Figure 10 – Boltaron and leather was tested to test code F2 whereas all other materials tested to test code F1. The graph shows the measured burn length. The control (unexposed) test was not performed for Royalite, Leather, and Sidewall Panel.

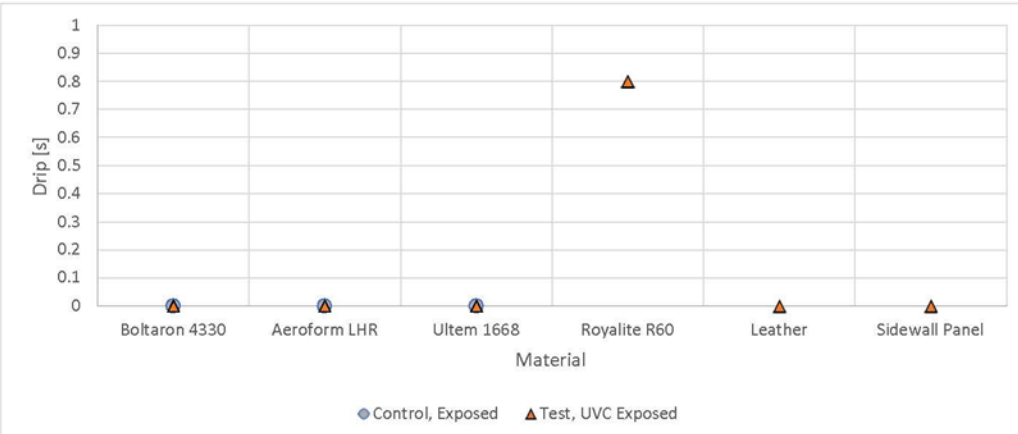


Figure 11 – Boltaron and leather was tested to test code F2 whereas all other materials tested to test code F1. The graph shows the measured drip time. The control (unexposed) test was not performed for Royalite, Leather, and Sidewall Panel.

Therefore, it can be concluded that there is no impact of the tested materials on flammability due to exposure to UVC at 254nm.

6. SEAT BELT PULL TEST

6.1 TEST SETTING

The seat belts are AMSAFE, Model No. 502751-1, FAA TSO C22g, rated for 3000lbf. It is important to note that the tested seat belts were not in new condition. The seat belts were positioned in the UVC chamber such that the ends with the stitching were fully exposed to UVC. This was done to study the potential deteriorating effects of UVC on stitching. Since this was a 3000lbf pull test, exposing majority of the seat belt that includes the stitches on at least one side is enough to create a potential weak spot. The exposition was carried out during Set 3b with the leather and sidewall materials which were used for flammability while the seat belts were retained for the pull test.

6.2 TENSILE STRENGTH RESULTS

Table 6 - Average irradiance and Cumulative Fluence for each material sample in the area used for flammability testing. Note that the leather has higher variance as it encompassed a larger area of the test bed.

Specimen ID	Material	Irradiance ($\frac{mW}{cm^2}$)	Total Time of Exposure $(seconds)$	Cumulative Fluence ($\frac{J}{cm^2}$)
17a	Seat Belt # 1	4.1 ± 0.1	171720	700 ± 10
17b	Seat Belt # 2	4.0 ± 0.1		690 ± 10

A total of 1 control (non-exposed) and 2 test (exposed) seat belts were subjected to loads to determine if the seat belts can withstand the rated 3000lbf of force.

Specimen ID	UVC Exposed	Breaking Load (lbf)	Failure Mode
17a	Yes (without the fold over)	3419lbf	Web failed; fiber pull out at edge
17b	Yes (with the fold over)	2888 lbf	Failed outside UV exposed zone, at loop
17c	No	3081lbf for 30s	Not taken to failure

Therefore, exposing the seat belt (including the stitching) does not compromise the rated load of the seat belts. Since the seat belts were aged and worn, the failure of specimen 17b at the non-exposed UVC region is not indicative of the integrity of the seat belt being compromised due to UVC exposition.

7. APPEARANCE EVALUATION

7.1 TEST SETT ING

The UVC exposition for appearance evaluation was conducted over two days spanning December 9, 2020 to December 11, 2020 at aero hygenx facility to complete Set 1 exposition comprised of Boltaron, Aerform, Ultem, and Royalite. A second session was conducted over two days spanning January 11, 2021 to January 12, 2021 to complete Set 2 comprised of Lexan 9604, Upholstery Fabric (Dark), Lexan FMR, Leather Lantal Navy Blue, Window Shade, aeroform (grey side), Upholstery Fabric (Light), and Lexan FST-9705. Finally, a third session was conducted over 6 days spanning February 5, 2021 to February 12, 2021 to complete Set 4 comprised of window shade, Ultem 9075, placard, and sidewall. Set 4 utilized lower intensity over a longer period. Set 5 was conducted between September 7, 2021 to September 9, 2021 and exposed a glass display of an avionics panel commonly found in a [redacted] flight deck. The set up was similar to what is shown in Figure 12 with the avionics display panel placed with the center of the panel at (17, 5) inches. All tests were witnessed by [redacted] via Microsoft Teams. The entire duration of exposition was recorded on Microsoft Teams with some data dropouts.

7.2 GRID IRRADIANCE M EASUREMENT

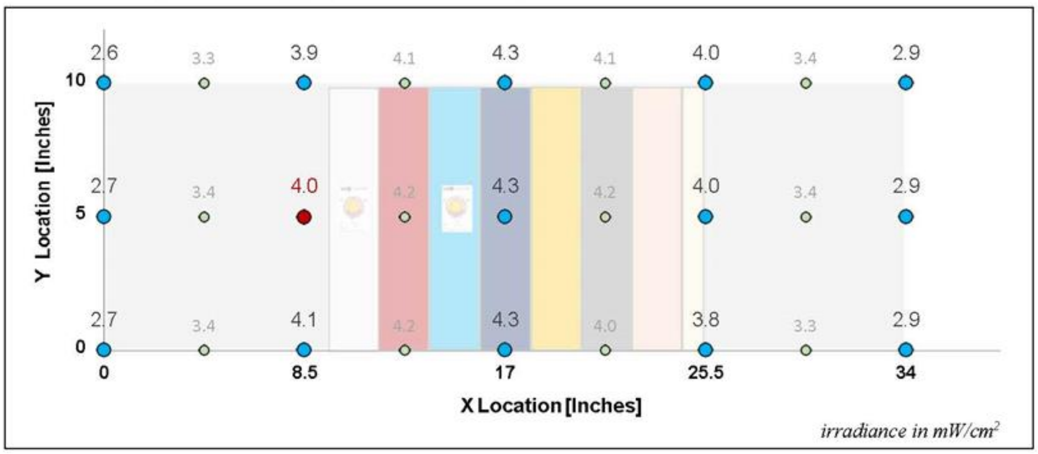


Figure 12 – The graph above shows the corrected irradiance measurements taken during **Set 2**. The material placement on the testbed is overlaid on the same graph. The reference measurement was taken at the location indicated with the red marker. The values show the steady state values in irradiance after the test chamber was allowed to reach a stable temperature and humidity. The UVC Dosimeter cards were placed until the first Stop point to determine transmissibility.

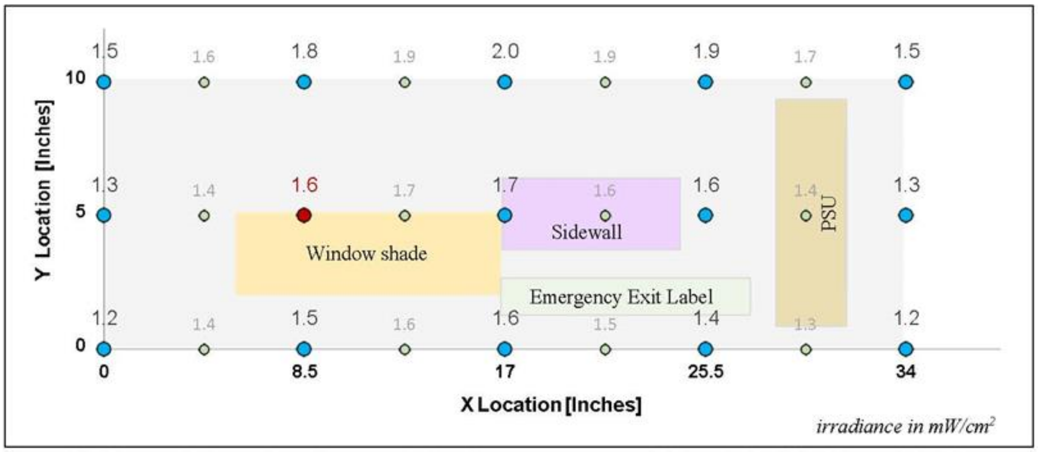
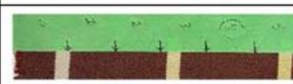
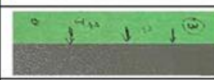
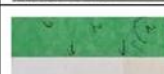
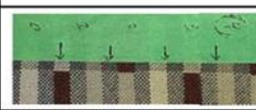


Figure 13 – The graph above shows the corrected irradiance measurements taken during **Set 4**. The material placement on the testbed is overlaid on the same graph. The reference measurement was taken at the location indicated with the red marker. The values show the steady state values in irradiance after the test chamber reached a stable temperature and humidity. This set utilized a lower irradiance to be more representative of actual irradiance on window shades and sidewall panels.

7.3 Appearance Test Results

The green highlight shows the level after which a determination of NSD has been made by the authors.

	Specimen ID	Material	Irradiance $(\frac{mW}{cm^2})$	Cumulative Fluence $(\frac{J}{cm^2})$							Exposed Sample
Set 1	2b	Ultem 1668	4.0	39	77	141	337	699			
Set 1	3b	Royalite R60	3.7	36	72	131	315	653			
Set 1	4b	Boltaron 4330	3.7	36	71	131	315				
Set 1	5b	Aeroform LHR (Beige)	3.6	35	70	128					
Set 2	1	Lexan 9604	4.1	47	95	145	198	248	298		
Set 2	6	Seat Fabric (Dark Side)	4.2	48	97	148	202	253			
Set 2	7	Lexan FMR	4.2	49	99	151	205	257	309		
Set 2	8	Leather	4.3	49	101	153	208	261	314	665	
Set 2	12	Aeroform LHR (Grey)	4.1	47	96	146					
Set 2	11	Window Shade (classic)	4.2	48	98						
Set 2	13	Seat Fabric (light side)	4.0	46	94	143	195				
Set 2	10	Window Reveal	3.9	45	92	140	191	238	287		

AIRCRAFT MATERIAL COMPATABILITY TO 254NM ULTRAVIOLET-C (UVC) LIGHT

Set 4	11	Window Shade (o coat)	1.7	46	94					
	11	Window Shade (1 coat)	1.7	46	94					
	11	Window Shade (2 coat)	1.7	46	94					
	14	Placard	1.5	42	85	130	174	217	261	
	15	Ultem 9075	1.5	41	83	126	168	210	253	
	16	Tedlar on Honeycomb Composite Panel	1.7	46	94	142				
Set 5	17	Avionics Display Panel	4.2	68	137	182	238	305		

In general, the appearance test was performed to 300J/cm² with stops at roughly every 50J/cm² to freeze the appearance. The goal was to determine the increment after which only negligible to slight discoloration (NSD) occurs. A secondary goal was to also determine if any textural (feel, cracks, peels, etc.) changes occurred. If data was available from the flammability and/or tensile test exposition, the appearance analysis was expanded to 600J/cm².

Materials did not exhibit significant change in texture. The only exception was Royalite R60 which exhibited a feel change after 653J/ cm² with the material becoming slightly more susceptible to registering sweat and fingerprint marks. However, no discoloration or appearance changes occurred.

Specimen ID	Material	NSD Fluence ($\frac{J}{cm^2}$)	Number of Disinfections after NSD Occurs At given fluence per disinfection		
			15 mJ/ cm^2	30 mJ/ cm^2	60 mJ/ cm^2
2b	Ultem 1668	699	46600	23300	11650
3b	Royalite R60	653	43533	21767	10883
4b	Boltaron 4330	315	21000	10500	5250
5b	Aeroform LHR	128	8533	4267	2133
1	Lexan 9604	298	19867	9933	4967
6	Upholstery Fabric (Dark)	253	16867	8433	4217
7	Lexan FMR 604-116	309	20600	10300	5150
8	Leather (last point Set 3b)	665	44333	22167	11083
12	Aeroform LHR (Grey Side)	146	9733	4867	2433
11	Window Shade (old interior)	98	6533	3267	1633
11	Window Shade (old interior, reduced irradiance)	94	6267	3133	1567
13	Upholstery Fabric (Light)	195	13000	6500	3250
10	Lexan FST-9705	287	19133	9567	4783
14	Placards	261	17400	8700	4350
15	Ultem 9075	253	16867	8433	4217
16	Tedlar on Honeycomb Composite Panel	142	9467	4733	2367
17	Avionics Display Panel	305	20333	10167	5083

Most materials exhibited NSD after being exposed to the highest tested fluence at ~300J/cm^2. However, there appears to be three materials where NSD occurs after lower amount of fluence. During Set 2 exposition, Window Shade (old interior style) showed NSD after 98J/ cm^2 of fluence. Since window shades are the furthest away from the UVC exposition source during aircraft application, it was hypothesized that reduced intensity and increased time of exposure while keeping the fluence a constant may produce more representative results. However, it was obseved after Set 4 exposition, that even at the reduced intensity while keeping energy constant, the determination of NSD can only be made after 94J/cm^2 which was in line with the previous determination. Next, for disinfection, since a multibarrier philosophy is expected to be adopted in the years to come, the impact of exposing the window shades with application of antimicrobial coating was also studied. It was determined that a single coat did not alter the discoloration progression of the window shade. However, a double coat of anti-microbial reduced the discoloration progression slightly. This is believed to be due to UVC energy being reduced as it traverses through the thin layers of the coating prior to reaching the underlying window shade surface. In conclusion, the fluence at which NSD occurs remains between 94-98J/ cm^2 for the window shade. Since the window shade will be exposed to only one of the passes in the Dual Pass Methodology, a full disinfection cycle would administer a fluence of only 15mJ/ cm^2. Therefore, NSD would occur after 6400 heavy disinfections. It should be noted that the window shade is from an old interior and the material is unknown.

Sidewall was also tested with reduced intensity during Set 4. It was determined that the sidewall showed NSD after being exposed to 142J/ cm^2 and to a less meticulous eye without a frame of reference may be acceptable to 191J/ cm^2. However, given the large surface area of the sidewall panel, a safe determination of NSD remains to be after 142J/ cm^2. Since the sidewall is exposed to both passes in the Dual Pass Methodlogy, a full disinfection would adminster a fluence of 30mJ/ cm^2. Therefore, NSD would occur after 4733 heavy disinfections.

Aeroform LHR Beige exhibited NSD after being exposed to 128J/ cm^2. However, Set 1 did not use a 50J/ cm^2 incremental test. Instead, subsequent stop was made at 307J/ cm^2. The change between 128J/ cm^2 and 307J/ cm^2 was observed to be drastic, however, based on the discoloration progression pattern on other materials, it can be ascertained that NSD can be made at a higher fluence than 128J/ cm^2 but definitely lower than the 307J/ cm^2. Therefore, an average number is being used to determine that Aeroform LHR would still arguably exhibit NSD after 200J/ cm^2. Since the usage of this material in the cabin is unknown, it is assumed that this material is exposed to both passes in the Dual Pass Methodology. However, since Aeroform LHR Beige would most likely be closer than the sidewall or window shade, an assumed value of 50mJ/ cm^2 per disinfection results in 4000 disinfections for NSD.

Leather was tested and did not show any signs of discoloration after the full test campaign which exposed the material to 314J/ cm^2 in Set 2. Since aisle leather seats are closest to the UVC source, it is estimated that after a single DPM, a total of 120mJ/ cm^2 (sidewall * 4) would be adminstered. Therefore, leather would show no discoloration after 2617 disinfections. During Set 3b, leather was exposed to 660J/ cm^2 to determine the impact on flammability. Although it was not the original intent, this test did reveal that leather maintains its color after being exposed to these levels. Therefore, it can be concluded that leather would not exhibit discoloration after 5500 disinfections.

Seat fabric showed NSD after 195-202 in the lighter regions of the fabric. Fabric that have white patches or lighter in color may exhibit discoloration after 1654 disinfections. It is recommended to continue to study seat fabric in newer materials as the fabric utilized for this study is much older and most likely did not use UV stabilization formula. The darker patches remain unaffected after 293-304J/ cm^2. On a pragmatic note, fabric would age and discolor more readily due to it being more susceptible to dirt accumulation and being more difficult to clean. Therefore, fabric discoloration due to UVC may not be of substantial importance as they may be replaced more often than leather seats due to soiling and other operational wear and tear.

Ultem 1668, Royalite R60, Boltoran, Lexan 9604, Lexan FMR, Emergency Exit Labels, PSU either did not show any discoloration or showed NSD after the highest cumulative fluence tested ranging between 253-317J/ cm^2. It was possible to expand the appearance analysis for Ultem, Royalite, and Boltaron to a cumulative fluence of >650J/cm^2 as data was available due to the materials being exposed for higher UVC for flammability and thermoplastic tensile strength tests. It was concluded that Ultem 1668, and Royalite continued to exhibit NSD after being exposed to 653-699J/ cm^2 which helps to expand the NSD disinfection number to 5000 for surfaces closer to UVC source and being exposed to both passes.

Avionics display panel did not show any discoloration after UVC exposure to 305J/cm^2. Note that both the glass and the display panel border was exposed.

In conclusion, most materials were observed to exhibit negligible to slight discoloration (NSD) after 5000 disinfections.

In a future revision of this report, it is recommended that the most susceptible materials identified in this report be evaluated for its specific application in the cabin for determination of proximity to UVC emitting source and also being exposed to two passes during a disinfection cycle. If the three criteria identified below are satisfied simultaneously, discoloration can start to materialize after 2500 disinfections:

i. Materials that show moderate to severe discoloration after 200-300J/cm^2 **and**
ii. Surfaces on the aircraft with those materials closer to the UVC source **and**
ii. Surfaces that remain unaltered between passes

However, intuitively there remains a very small subset of surfaces in the cabin that would simultaneously meet the above three criteria.

The appearance results depicted in this section are limited to what is considered an acceptable level of discoloration as evaluated by the authors.

8. TRANSMISSIBILITY TEST

8.1 TEST SETTING

The transmissibility test was performed during Set 2. The Intellego Technologies UVC Dosimeters were placed behind the two Lexan samples as shown in Figure 12.

8.2 TRANSMISSIBILITY TEST RESULTS

As UVC behaves differently compared to visible light, a material that may be transparent visible may be opaque for UVC. The goal was to determine how much energy was transmitted through the window dust pane material: Lexan FMR. Two dosimeter cards were placed behind Lexan FMR and Lexan 9604, respectively. The UVC energy incident on these materials during Set 2 Stop 1, were calculated to be 49000 and 47000 mJ/cm^2, respectively. The first color change of the UVC Dosimeters occurs when the color indicator registers a fluence of ~25 mJ/cm^2, second and third color change would indicate that fluence of 50mJ/cm^2 and 100mJ/cm^2 was registered by the UVC Dosimeters.

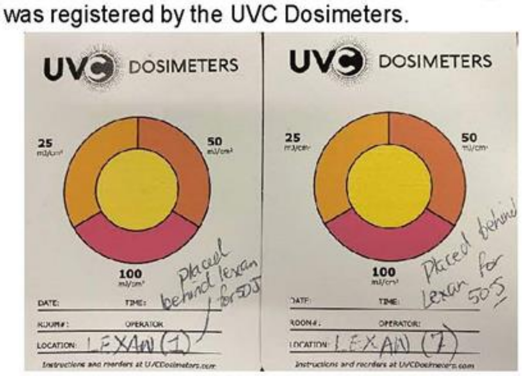


Figure 14 – UVC Dosimeters placed behind Lexan 9604 (left) and Lexan FMR (right) showing no color change of the center circle after being exposed to 49000-47000 mJ/cm^2 (i.e. after 3 hours). If the cards were placed in front of the material, it would have taken 6 seconds for the first color change to occur. This demonstrates the opaque characteristic of this material to UVC frequency.

Since the material is placed between the UVC source and the UVC Dosimeters, the three-color changes would then indicate that 0.05%, 0.1%, and 0.2% were transmitted through the material. The UVC Dosimeters placed behind each type of Lexan exhibited no color change confirming that UVC transmission is negligible to none. Therefore, it can be concluded that UVC will not permeate beyond the dust pane of the windows permitting window shades to be left open during disinfection for one of the passes.

9. CONCLUSION

This research and development project exercised novel methodologies to test the impact of ultraviolet-c light on aircraft materials. The methodology utilized a combination of existing well-established standards for material property testing while utilizing new experimental methodologies to efficiently expose materials to large amounts of UVC in a span of a few weeks.

The results of the investigation indicate that exposing materials to multi-year equivalent fluence of UVC light does not impact tensile strength, stress cracking, flammability of thermoplastics; does not impact tensile strength of passenger seat belts. Material appearance is observed to be affected after 5000 disinfection cycles and can be characterized as negligible to slight discoloration after these number of cycles. For reference, one disinfection cycle at the sidewall distance (furthest from source) is the equivalent of 30mJ/ cm^2 which is the equivalent of 4-6x, 99.9% lethal fluence for SARS-CoV-2 virus. This is a conservative methodology of achieving high inactivation of the virus underlying the current threat but is also sufficiently high to neutralize other harmful pathogens studied to date and expected to arise in the future. As operators begin to adopt UVC disinfection technology, further optimization of this dosage per disinfection cycle can be carried out to prolong the time for NSD, if needed. Lastly, it is concluded that UVC light from inside the cabin does not permeate through the window dust pane which allows window shades to be open during disinfection allowing both the window shade and the window dust pane to be disinfected.

As per CDC guidelines published as of April 5, 2021 in the context of COVID-19, aircraft cabin meets the criteria for indoor spaces that require disinfection. Furthermore, disinfecting aircraft cabin can help curtail the transmission probability of diseases that rely more heavily on the fomite transmission vector as well as reducing the probability of disease transmission within the aircraft cabin environment due to a novel pathogen that may arise in the future.

The authors conclude that UVC disinfection is a safe and effective methodology for aircraft cabin disinfection and an autonomous applicator can ensure human beings are not inadvertently exposed, and consequently will also not require PPE unless in an emergency situation where manual intervention of the UVC operation needs to take place.

G Operator survey

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
Liquid spray and wipe: Cleaned via liquid disinfectant on every turn and RON. Products used include: Calla 1452 and SANICIDE EX-3; Electrostatic fogging is used in the cabin only. Products used: BactroKill and SurfaceWise2	Cleaning is accomplished by cleaning crew: all vendors.	Same methods are used on the flight deck, but no electrostatic cleaning. Vendors are not allowed to bring liquid cleaner onto flight deck. They must put in on the applicators first.	Cleaning is accomplished by cleaning crew: all vendors.	Cleaned via liquid disinfectant on every turn and RON. Deep cleaning performed every 7 days when BactroKill is used. Every 30 days when SurfaceWise2 is used. Deep cleaning involves more surfaces than the 'normal' turn and RON cleaning. SurfaceWise2 is only used in 1 hub. BactroKill is used at 12 outstations. Each airplane is on a	Cleaned via liquid disinfectant on every turn and RON. Same as above. No electrostatic fogging
Electro-Static Spraying (ESS), using Jon-Don Matrix #3 biocide cleaner.	Cleaning Crew (company personnel and third-party authorized representatives.)	Liquid wipe down with lint-free cloth using alcohol-isopropyl (at least 70% alcohol.)	Cleaning Crew (Company personnel and third-party authorized representatives) on overnights; Pilot option during revenue operations.	Prior to each revenue flight and overnights.	During revenue operations and overnights.
Airline is using Byotrol 24 for cleaning aircraft cabin surfaces, galleys, and lavatories and Flight Deck. In addition, airline is using Electrostatic Sprayers each evening.	Cleaning crew and Maintenance.	Flight Deck is primarily cleaned with damp liquid wipe with Byotrol 24.	Cleaning crew and maintenance	Each flight and each evening	Each evening.
Electrostatic spraying with CALLA 1452 (Matrix 3) followed by a wipe down; Customers are provided with sanitizing wipes for cleaning of personal space.	Cleaning crew, flight attendants, and passengers	Wipe down with CALLA 1452 (Matrix 3)	Cleaning crew pilots.	Each flight.	Daily and during crew changes.

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
Liquid spray, liquid wipe, electrostatic spraying – predominantly using Matrix 3. Celeste EX-3 as a backup. International, multiple chemicals as approved by local jurisdiction. Lysol wipes will begin by EOM Nov for flight attendant use. Customers have access to Purell wipes.	Cleaning crew, flight attendants, passengers, and maintenance technicians all performing various aspects of the disinfectant process.	Liquid wipe (Matrix 3) with Far UV applications in test. Pilots have access to Fresherize disinfectant wipes.	Cleaning crew performs liquid wipe of non-flight critical surfaces. Maintenance technicians complete a wipe down of all surfaces on an approximate 30 day basis.	Prior to every flight.	Non-flight critical surfaces: nightly. Full wipe down ~ 30 days.
Electrostatic spraying	Cleaning crew (Business Partner.)	Wiping down is performed using approved cleaners.	Airline Tech Ops (Maintenance) Crewmembers.	Once every 15 days.	Daily.
For passenger aircraft, electrostatic misting with PurTabs product. For spot cleaning in between flights, the cabin crew have paper towels and disinfectant solution in spray bottles available to them – ZEP Aviation RTU cleaner disinfectant. Also, personal alcohol disinfecting wipes made by Sani professional are available (SANI-HANDS) to clean smaller areas.	Contract cleaners are primary for major cleaning/disinfection. Flight Attendants perform spot cleaning. Each passenger is given an alcohol wipe to clean their seat area (tray table, overhead panel, seat belt, window shade, etc.)	The cockpit is cleaned by wiping surfaces with undiluted isopropyl alcohol.	Maintenance cleans the cockpit. Pilots have access to the same cleaning supplies for additional cleaning as needed.	Passenger aircraft cabins are cleaned daily (or verified previously cleaned) by contract cleaning crew during the Remain Overnight (RON) turn. Electrostatic spray cleaning is conducted by the same group at the same interval, or as needed, in the event of potential contamination. In between flights, the flight attendants have access to cleaning	Maintenance completes a thorough cockpit cleaning prior to the crew's shift. The pilots have access to the same cleaning supplies to clean as needed during their shift.
Type 1 aircraft-Liquid spray Bacoban. The aircraft is cleaned from the cockpit all the way to the hand rails on the boarding stairs. Floor mats, carpet, armrest seats, sidewalls etc. Vacuum, wipe downs, and spray defoggers are used. All with approved products. Most recent right now is research. We have 8 post flight services and 2 heavy services including restorations of the research mats. Type 2 & 3 Aircraft- Wipe down with cloth sprayed with Clean Quick Broad Range Quaternary	Type 1 Aircraft - Our airplane is cleaned and sanitized prior to the first flight.(Night before). I have been using cleaning companies that work the aviation community. On days that we do multiple flights, the plane will be cleaned and sanitized along with detailing. The cleaning is performed by employees of the servicing company. It	Type 1 aircraft - Bacoban® For Aerospace Type 2 aircraft- 1 ounce Quaternary Sanitizer to 4 gallons water. We have pH strips available to ensure the correct dilution of 200 ppm. Spray the Quaternary Sanitizer solution onto a clean rag and hand wipe all critical surfaces. Tyoe 3 aircraft- Wipe down with cloth sprayed with Clean Quick Broad Range Quaternary Sanitizer Concentrate.	Type 1 aircraft - Our airplane is cleaned and sanitized prior to the first flight.(Night before). I have been using cleaning companies that work the aviation community. On days that we do multiple flights, the plane will be cleaned and	Type 1 aircraft – Cockpit and cabin. Our airplane is cleaned and sanitized prior to the first flight.(Night before). On days that we do multiple flights, the plane will be cleaned and sanitized along with detailing.	Type 2 aircraft- Cockpit every night at the completion of preflight checks.Type 3 aircraft- Cockpit/Cabin at end of every flying day.

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
The cabin is disinfected via liquid spray utilizing Calla 1452	Disinfection is performed by fleet service in hub Flight attendants, ground personnel, and pilots may assist in out stations.	Floors and all non-control surfaces are cleaned via liquid spray utilizing Calla 1452. Control surfaces are cleaned using Clorox wipes	Non- control surfaces are cleaned by fleet service. Pilots perform the cleaning of the flight controls.	Cabin: is wiped down each flight and nightly.	Non-control surfaces disinfected daily. Flight controls wiped down whenever a crew swap takes place.
Cargo Aircraft. No cabin disinfection is being performed.	Cargo Aircraft. No cabin disinfection is being performed.	When accepting the aircraft, crewmembers clean high touch surfaces with Clorox wipes. Oxygen masks are cleaned with Sani-com cleaning towels Hand sanitizer is provided on flight deck Crewmember were also issued personal bottles of hand sanitizer. Hand sanitizer options: 1. Bio silk health 2. Zone defense 3. BAC Stop 3A (1 gallon bottle for refill staged at crew reporting stations)	Flight crew and load master perform cleaning of high touch surfaces when accepting the aircraft. We run 1 to 3 shifts per day. Cleaning vendor is used to fog the flight deck if an employee has a COVID symptoms 24 hours after	Cabin: cargo aircraft- no cabin disinfection is being performed.	Cockpit: Flight crew and load master perform cleaning of high touch surfaces when accepting the aircraft. We run 1 to 3 shifts per aircraft per day. Cleaning vendor is used to fog the flight deck if an employee has a COVID symptoms 24 hours after operating the aircraft.
N/A - Cargo only	N/A - Cargo only	Liquid spray SaniCide EX is being used.	Cleaning is performed on arrival at hub by contract cleaners using our cleaning product.	Cabin: N/A Cargo - only	Cockpit: Cockpit is being cleaned on arrival to hub and crews also clean at their discretion prior to their flights.
We are using Lysol Multi Surface Cleaner disinfecting as liquid spray. For Aircraft Fogging we use VitalOxide after COVID/Close Contact related flights.	Cleaning Crew/Ramp Agents. Aircraft fogging is done by CCI Industrial Services, LLC	Alcohol wipes and Lysol wipes.	Maintenance.	After each flight	After each flight day.

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
Lavatory and supernumerary areas are cleaned using Sanicide EX3. Liquid disinfectant is sprayed on the surface then wiped off. Cargo holds are not disinfected.	Depending on the location it is performed by contract cleaning vendors or aircraft maintenance personnel.	Same chemical as above. Disinfectant is sprayed on low lint rag and cockpit surfaces are wiped down; this prevents excess fluid entering sensitive electronic controls.	Depending on the location it is performed by contact cleaning vendors or aircraft maintenance personnel.	Disinfecting procedures are completed after each flight in hubs domestically and after each international arrival globally. Flight crews are also supplied with disinfecting wipes that they can use upon arrival at the aircraft to touch up the cockpit and supernumerary area.	
Electro static spraying (ESS) with Antimicrobial Shield Zoono Z-71 Formula (Ready to use)	Cleaning crews perform at all stations except for one maintenance Base, which is performed by airline maintenance	Microfiber cloth dampened with EX3/isopropyl alcohol wipe	Cleaning crews	After each flight.	Cleaning crews, daily.
Liquid spray and electrostatic spraying. Sanicide EX3, began transitioning to Byotrol 24 as of 11/2.	Cabin Cleaning Crew	Liquid Spray into a cleaning towel and then wiping down. Sanicide EX3, began transitioning to Byotrol 24 as of 11/2. IPA wipes from crew kits may be used	Cabin Cleaning Crew; Flight Deck crew as desired using IPA wipes in crew kits	Each turn flight except in AK Arctic Region. All RONs. Electrostatic spray only takes place on RONs not on turns	All turn flights, as needed, except in AK Arctic Region. All RONs
The following methods are being used in the cabin; liquid spray, Electrostatic fogging/spraying. Due to the list of approved products available to our codeshare partner and that the use of product changes, our codeshare partner would be able to provide an accurate list of product names	Third party vendors for overnight cabin disinfection and either codeshare partner employees and/or third party vendors for cabin disinfection during the day and during aircraft operations.	The following methods are being used in the cockpit; liquid spray (sprayed onto a cloth before applied to any surface in the cockpit) and liquid wipes	Third party vendors for overnight cockpit disinfection and either codeshare partner employees and/or third party vendors for cockpit disinfection during the day and during aircraft operations.	Between flights, daily (between turns in hubs) and each night for aircraft that RON at a hub.	Between flights, daily (between turns in hubs) and each night for aircraft that RON at a hub.
We are Cargo only. We do not disinfect the cargo area.	N/A	Radian alcohol wipes.	Pilots and mechanics.	N/A	Daily and each flight, as determined by the flight crew.

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
Airline wipes down seats, trays and other common touched surfaces. We also have the ground handler use a fogger as well. We utilize a liquid spray of Celeste Sani-Cide EX-3 RTU. The chemical is sprayed directly onto surfaces except for electronics screens or leather surfaces. We allow the chemical to rest on the surface for the appropriate dwell time and buff the area clean with a microfiber towel, For areas with screens or sensitive electronic equipment, the chemical is sprayed onto a microfiber cloth and applied to treatable surfaces.	The cabin crew and ground handler disinfects the cabin after the passenger disembarks	The flight deck is wiped down with Clorox wipes or equivalent. The ground handler will lightly fog the flight deck entry area.	The crew, maintenance and sometimes airline's ground personnel will disinfect the flight deck.	The cabin will be disinfected when there is a crew change (Galleys), when passengers disembark or when ground cleaning is schedule.	The flight desk will be disinfected when there is a crew change or when ground cleaning is schedule.
Certain private operators are utilizing Liquid Spray and Disinfectant Wipe Downs	All cabin disinfection is done by Pilots and Maintenance personnel for all operators	Certain private operators are utilizing Liquid Spray and Disinfectant Wipe Downs	Pilots and maintenance personnel do all disinfecting in cockpit for all operators.	Disinfectant is completed on all Pre/Post flights	Disinfectant is completed on Pre/Post Flights
Liquid spray – Calla 1452 disinfectant; Fogging (select MX bases - Backtrokill plus	Ground/cleaning crew, maintenance (fogging)	Liquid spray onto cloth – Calla 1452 disinfectant	Ground/cleanin g crew	Hub turn cleans, RON cleans	Hub turn cleans, RON cleans
Airline utilizes two compositions in either a liquid spray or moist wipe depending on application environment and safety to end user.	Airline utilizes a cleaning crew supervised by maintenance personnel. In addition, flight attendants.	Airline utilizes moist wipes.	Airline pilots and maintenance personnel.	Between each revenue flight.	At each maintenance opportunity.
CALLA 1452 or Backtrokill Plus applied during electrostatic spraying; anti-microbial spray using Surface Wise 2 (limited to 1 hub currently but will expand)	Cleaning crew during most turns, maintenance while in maintenance overnights	Liquid wipe (alcohol wipes)	Pilots, maintenance while in maintenance overnights	Each flight	Daily, when flight deck crews change
Byotrol 24- wipe all contact surfaces	Cleaning crew during most turns, maintenance while in maintenance overnights	Liquid wipe (alcohol wipes)	Pilots, maintenance while in maintenance overnights	Each flight	Daily, when flight deck crews change
Matrix #3 Ready to Use (diluted); applied by liquid spray/wipe and electrostatic spraying	Cleaning crew during most turns, maintenance while in maintenance overnights	Liquid wipe (alcohol wipes)	Pilots, maintenance while in maintenance overnights	Each flight	Daily, when flight deck crews change
CALLA 1452 Ready to Use (diluted); applied by liquid spray/wipe and electrostatic spraying; anti-microbial spray (testing) using Zoono-Z71	Cleaning crew during most turns, maintenance while in maintenance overnights	UV light, flight deck spray cloth and wipe down (CALLA 1452), liquid wipe (alcohol wipes)	Cleaning crew, pilots, maintenance while in maintenance overnights.	Each flight	Daily, when flight deck crews change

Disinfecting Project

1) What disinfecting methods are you using in the cabin (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if available.	2) Who performs the cabin disinfection (cleaning crew, passengers, flight attendants, maintenance, etc.)?	3) What disinfecting methods are you using in the cockpit? (e.g., liquid spray, liquid wipe, UV, electrostatic fogging or spraying, ionization, etc.)? Include product name if	4) Who performs the cockpit disinfection (cleaning crew, pilots,	5) How frequently are each of those	
				Cabin	Flight Deck
1) We use Bioesque Botanical Disinfectant to clean and Disinfect our high-touched hard surfaces of the aircraft on overnight cleanings. This is a spray and wipe application. 2) We electrostatically spray ZipChem Calla 1452 disinfectant. 3) We still perform turn cleaning of some high touchpoint locations (Spray and wipe tray tables and lavatories) in the cabin using Celeste Sanicide EX3 with Ground Ops or their contractors. 4) Celeste Sanicide EX3 Disinfectant is provided on board for Crew use (unscheduled)	Aircraft Appearance (Maintenance) or our Overnight Cleaning Contractors. Ground personnel perform turn cleaning.	We disinfect with a spray and wipe technique using Bioesque Botanical disinfectant nightly. Calla 1452 disinfectant is also spray and wipe applied at 30 days and electrostatically sprayed every 90 days.	Appearance technicians or their contractors	Turn cleans between flights. Disinfection with spray and wipe application occurs on RON nightly. Electrostatic application of disinfectant occurs every 30 days in Cabin.	Disinfection with spray and wipe application occurs on RON nightly. Electrostatic application of disinfectant occurs every 90 days in Flight Deck.
We use liquid spray and liquid wipe	Contractors	Liquid wipes	Contractors	Daily, assuming aircraft has flown	Daily, assuming aircraft has flown
Clean and wipe hard surfaces- Sani-cide EX3, Electrostatic Spraying Departures - Calla 1452; Anti-microbial Coating application - Zoono Microbe Shield	3rd party contracted cabin cleaners	70% IPA wipes; UVC light - AuvCo Blade (254nm)	3rd party contracted cabin cleaners	Wipe and Clean every departure and RON; Electrostatic Spray every departure and RON; Anti-microbial coating Every 7 days per aircraft.	IPA Wipes- Every RON in the line and regional stations; UVC - Hub RON
N/A	N/A	Liquid wipes - Braha Industried - 75% alcohol wet wipes.	Crew	N/A	Each crew change