

# **Clean Airplane Program – Live Virus Validation Testing**

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# Abstract

The COVID-19 global pandemic has significantly encumbered many industries including air travel and aviation, with drastically fewer travelers flying today than in the past several years. In an effort to enhance safety and restore confidence in air travel, Boeing's Clean Airplane Program undertook studies to validate the efficacy of various disinfection technologies intended to combat SARS-CoV-2 – the virus that causes COVID-19 – on commercial aircraft cabin surfaces. Disinfection technologies included disinfectant wiping, antimicrobial coatings, ultraviolet light, and electrostatic sprayers. While transmission of SARS-CoV-2 through contact from surfaces may be a less common infection pathway<sup>1</sup>, successful disinfection technologies applied to high-touch surfaces remain an important cornerstone to the enhancement of the safety and comfort of passengers, crew, and personnel on commercial aircraft.

This paper discusses these various disinfection technologies and reviews the results from validation testing conducted by Boeing and the University of Arizona. Validation testing was performed in an airplane interior mockup, a production airplane, and laboratory settings, using both surrogate viruses, bacteriophage MS2 and human coronavirus HCoV-229E, and the novel human coronavirus SARS-CoV-2. MS2 was evaluated in an interior mockup and production airplane at Boeing's facilities. MS2, HCoV-229E and SARS-CoV-2 were evaluated in controlled laboratory environments by the University of Arizona.

Results show that the airplane environment can be effectively disinfected with appropriate methods. Variations in results are seen with treatment, application and to some degree, surface

materials. Disinfectant wiping is shown to be highly effective with greater than 4 log<sub>10</sub> (> 99.99%) reduction against HCoV-229E. Several antimicrobial coatings show close to 4 log<sub>10</sub> (99.99%) reduction against HCoV-229 in just 30 minutes, and Boeing prototype polymer P13 showed nearly 4 log<sub>10</sub> (99.99%) reduction in 30 minutes and nearly 5 log<sub>10</sub> (99.999%) in 60 minutes against SARS-CoV-2. Ultraviolet light (UV-C, 222 nm) technology is shown to be highly effective against MS2 and HCoV-229E with greater than 2 log<sub>10</sub> (99%) or 3 log<sub>10</sub> (99.99%) reduction being achievable at appropriate energy dose levels. Electrostatic sprayer application using chemical disinfectant Calla 1452 followed by a quick cloth wipe showed greater than 2 log<sub>10</sub> (99%) reduction against HCoV-229E. The test results show that these technologies and applications are highly effective in eliminating key viruses on representative aircraft surfaces. While MS2 and HCoV-229E are similar to SARS-CoV-2, additional data using SARS-CoV-2 will confirm the efficacy of these treatments further and draw even stronger conclusions.

# Introduction

The advent of the COVID-19 global pandemic has significantly impacted global, regional and domestic air travel. At the time of this writing, the United States Transportation Security Administration (TSA) checkpoint traveler numbers for 2020 and 2019<sup>2</sup> show passenger traffic has reduced to between 30% and 40% of the levels it was a year ago during the same week with the lowest levels close to 4% during mid-April 2020. This has spurred an imperative across the air travel industry to enhance protections at multiple stages of the travel journey to minimize health risks to travelers, airport staff, ground crew, airline personnel, and to restore confidence in air travel.

Boeing's Clean Airplane Program and Validation Testing efforts focus on enhancing protections in the airplane cabin, flight deck and cargo compartments using products, technologies and methods for cleaning and disinfection. While many of the products, technologies and methods have been previously evaluated in laboratory environments, it is essential to validate the efficacy of these in representative mockup and production airplane environments, allowing Boeing to make the best cleaning and disinfecting recommendations to the airlines.

The disinfection technologies considered under Boeing's Clean Airplane Program – disinfectants, antimicrobial coatings, ultraviolet light, and electrostatic sprayers – were chosen based on known or anticipated efficacy against SARS-CoV-2, equivalent viruses or pathogens, and the range of methods by which they can be applied to commercial aircraft surfaces. Disinfectants are expected to be effective according to the Environmental Protection Agency's (EPA) List N<sup>3</sup> and require manual application. The compatibility and limitations of selected disinfectants on aircraft materials and components<sup>4</sup> were also considered. Antimicrobial coatings offer persistent protection on surfaces, and require initial application followed by periodic reapplication. Electrostatic sprayers provide a way to disinfect large surface areas of the aircraft cabin consistently and efficiently<sup>5</sup>. Finally, ultraviolet light (UV-C, 222 nm) provides an effective treatment against viruses without the damaging effect on skin or eyes<sup>6</sup>, and can cover many surfaces rapidly within an aircraft.

Boeing partnered with the University of Arizona to validate the efficacy of various disinfection technology solutions and to authenticate the test preparation, procedures and results. Dr. Charles Gerba, Professor of Environmental Science at the University of Arizona, was the principal investigator in this partnership and is a leading academic figure in virology, known for his methodologies in pathogen detection in food and water, and pathogen occurrence in households and risk assessment<sup>7</sup>. The studies undertaken were conducted in an airplane interior mockup and

production airplane using the surrogate virus MS2, and later in laboratory settings using MS2, human coronavirus HCoV-229E and the novel human coronavirus SARS-CoV-2.

The surrogate virus MS2 has a long and proven history of use in applications since the 1980s as tracers in groundwater<sup>8</sup>, waste/water treatment plants, and in academic studies to trace movement of pathogenic viruses in offices, hotels, health care facilities, and hospitals. MS2, a non-enveloped virus, is also a common viral surrogate for Norovirus and Rhinovirus, known for causing gastroenteritis and the common cold, respectively. MS2 is easy to work with, harmless to humans, and shares many features with eukaryotic viruses<sup>9</sup>, which have genetic material contained in an enveloped nucleus. MS2 can be grown to high levels allowing easier determination for amount of viral reduction<sup>10</sup>. While MS2 exhibits behavior similar to SARS-CoV-2 in some regards, it is also known to be more robust and resistant than SARS-CoV-2. As such, it is expected that these technology solutions will have a higher likelihood of killing HCoV-229E and SARS-CoV-2, both enveloped viruses, in comparison to MS2.

In July 2020, testing was conducted in a representative Boeing 787 cabin interior mockup at the Aircraft Integration Center (AIC) in Everett, Washington and on a Boeing 737 production airplane interior at Boeing Field in Seattle, Washington. The efficacy of disinfectants, antimicrobial coatings, electrostatic sprayers and ultraviolet light was evaluated on various high-touch cabin surfaces such as armrests, bins, lavatories, seats, tray tables, window buttons, and galleys. Subsequent testing carried out at the University of Arizona's Water & Energy Sustainable Technology (WEST) Center facility in Tucson, Arizona helped corroborate the testing performed at Boeing and confirmed efficacy against SARS-CoV-2.

# Test Procedures

# Mockup Testing

Mockup testing was conducted in a representative Boeing 787 cabin interior at the Aircraft Collaboration Center (AIC) in Everett, Washington on July 16, 2020. The mockup area represented the forward interior section of a Boeing 787 aircraft between doors 1 and 2 with representative sidewalls, bins, outboard seat rows, and a lavatory. A separate area was also available with a flight crew rest area containing a crew attendant seat and tray table. Bin assemblies and electronically dimmable window buttons were also placed on the floor to allow for proper inoculation of MS2 on these surfaces without runoff. Separate sections of the mockup were designated for each category of treatment being tested. Antimicrobial coatings were assigned to surfaces on the left hand outboard side of the mockup, and ultraviolet light was assigned to the separate crew rest area containing a flight crew seat and tray table. Refer to Appendix, Photographs A1-A3.

In each section, test surfaces were marked off in four square inch areas using tape, and designated for a particular treatment or control. To eliminate testing biases, randomized identification labels were generated for each treatment or control and placed adjacent to the prepared surfaces accordingly. All surfaces were initially cleaned using 100% isopropyl alcohol to eliminate any contamination prior to testing. General cleanliness of the mockup was also verified using Adenosine Triphosphate (ATP) testing of random surfaces to rule out any background contamination. A total of 174 samples were collected in support of mockup testing.

The University of Arizona prepared MS2 virus cultures at the WEST Center lab in Tucson, Arizona in the week prior to testing and dispatched the cultures in test tube vials that were packed in an ice cooler. The cultures arrived overnight in Everett, Washington one day prior to testing. It was necessary to keep the MS2 virus at an optimum temperature of 4 degree C or lower in order to keep the virus viable<sup>11</sup>. The MS2 virus was accompanied by 3M neutralized sponge sticks used for taking samples. Each 3M neutralized sponge stick was individually sealed in a clear plastic bag containing a 10  $\mu$ L solution of letheen broth to neutralize any residual disinfectant action once samples were taken.

Testing involved the following treatment categories:

- Antimicrobial coatings (Boeing prototype polymer P6 and four market-available third-party coatings)
- Disinfectant wiping (isopropyl alcohol 70% and Calla 1452)
- Electrostatic sprayer (using Calla 1452 disinfectant),
- Ultraviolet light (222 nm).

The specific treatments were chosen based on availability at the time of testing, active interest from the industry or airlines, chemical constitution, and compatibility. The antimicrobial coatings were chosen based on availability – Boeing polymer P6, an early developmental prototype of a Boeing antimicrobial coating and four third-party coatings were available, several with active interest from the industry or airlines. Disinfectants were chosen based on the active ingredient, isopropyl alcohol or quaternary ammonium compound, and being widely available in the open market. For electrostatic sprayers, Calla 1452 was the only product tested and deemed compatible at the time of testing. Ultraviolet light 222 nm was considered for its efficacy against viruses, and for its additional consideration given to personal safety, effects from electromagnetic interference, and ozone generation.

Antimicrobial coatings were applied to seat armrests, bin latches, seat cushions (fabric), seat backs (thermoplastic), seat tray tables, and electronically dimmable window buttons. These surfaces were pre-treated with each antimicrobial coating in accordance with the manufacturer's product label, and evenly sprayed on the surfaces approximately 24 hours prior to testing to allow for sufficient drying. On test day, each antimicrobial surface was inoculated with 20  $\mu$ L of MS2, then allowed to dry to note time t=0. Samples were subsequently taken at 20 minute, 60 minute and 360 minute time intervals to determine efficacy of each coating at the designated time interval. These time intervals were selected to determine the speed and efficacy of these coatings, and to align with the EPA's performance requirements of a minimum 3 log reduction within one to two hours in support of registration of antimicrobial coatings<sup>12</sup>. Other time points help determine the kill speed allowing for further comparisons between products. Control surfaces were left untreated with any antimicrobial coatings, inoculated with 20  $\mu$ L of MS2, allowed to dry, and then sampled at 60 minute time intervals.

Disinfectant wiping was applied to seat armrests, bin latches, seat cushions (fabric), seat backs, seat tray tables, electronically dimmable window buttons and several lavatory surfaces (faucet, counter, toilet seat lid, waste flap). Test areas were first inoculated with 10  $\mu$ L of MS2, allowed to dry, then wiped with a cloth saturated with isopropyl alcohol 70% or Calla 1452, allowed to dwell for 10 minutes in accordance with EPA List-N and the manufacturer's product label, and then finally sampled. The noted disinfectants represent two types based on chemical constitution –

isopropyl alcohol (isopropyl alcohol 70%) and quaternary ammonium compound (Calla 1452). Wiping of each disinfectant consisted of two basic application methods – a heavy wipe and a light wipe. A heavy wipe involved a vigorous scrub over the surface in accordance with EPA List-N guidelines and product labels, while a light wipe was performed in a quick and hastened manner intended to be a reduced-effort application.

An electrostatic sprayer, ESS SC-EB, using the disinfectant Calla 1452 was applied to seat armrests, bin latches, seat cushions (fabric), seat backs, seat tray tables, electronically dimmable window buttons. Test areas were first inoculated with 10  $\mu$ L of MS2, allowed to dry, then sprayed, allowed to dwell for 10 minutes, and then finally sampled. Spray from the electrostatic sprayer was applied using two basic methods – a heavy spray and a light spray. A heavy spray was applied by passing the spray nozzle over a targeted surface three times back and forth over a 90-degree arc, while a light spray was applied by passing the spray nozzle over a targeted surface three times back and forth over a 90-degree arc.

Ultraviolet light at 222 nm was applied to seat cushion and seat tray table surfaces. These surfaces were first inoculated with 10  $\mu$ L of MS2, allowed to dry, then irradiated with an average of 1,400 mJ/cm<sup>2</sup> of energy dosage, and finally sampled. The average energy was dosed at 2.5" distance from each surface for 400 seconds.

MS2 remains relatively stable for up to 24 to 48 hours once applied so it was important to complete testing and return the samples to the University of Arizona for analysis immediately following conclusion of testing. All samples were packed in an ice cooler and shipped back to the University of Arizona's WEST Center in Tucson, Arizona overnight for analysis. Samples were assayed and results provided within a few days after the samples were received.

# Airplane Testing

Airplane testing was conducted on a 737 Boeing production aircraft designated for flight testing at Boeing Field in Seattle, Washington on July 28, 2020. The aircraft contained a complete and functional interior configuration. Separate sections of the aircraft were designated for each category of treatment being tested. Antimicrobial coatings were assigned to surfaces between seat rows 22, 24 and 26. Disinfectant wiping was assigned to seat rows 12, 14 and 16, lavatories A, D and E, and the aft galley. Electrostatic spray was assigned to seat rows 6 and 9. Ultraviolet light was assigned to the seat row 10 and the forward lavatory. Refer to Appendix, Photographs and Figure, A4-A10.

Test surfaces were marked off, cleaned and verified in the same manner as described in the mockup testing above. Additionally, samples were taken from random locations within the aircraft cabin – seat 3A sidewall, seat 5A armrest, 28D bin face, 30F bulkhead wall – to review background contamination levels. A total of 176 samples were collected in support of airplane testing.

The University of Arizona prepared and shipped MS2 virus culture and 3M neutralized sponge sticks in support of testing, similar to what was described above for mockup testing.

Testing involved the following treatment categories:

- Antimicrobial coatings (Boeing prototype polymers P13, P11, and three third-party coatings)
- Disinfectant wiping (isopropyl alcohol 70% and Calla 1452)
- Electrostatic sprayer (using Calla 1452 disinfectant)
- Ultraviolet light (222 nm).

The specific treatments were chosen based on availability at the time of testing, active interest from the industry or airlines, chemical constitution, compatibility, and to supplement the testing completed in the mockup.

Antimicrobial coatings were applied to seat tray tables only. These surfaces were pre-treated with each antimicrobial coating in accordance with the manufacturer's product label, typically sprayed on evenly approximately 24 hours prior to the testing to allow for sufficient drying time. On test day, each antimicrobial surface was inoculated with 20  $\mu$ L of MS2, then allowed to dry to note time t=0. Samples were then taken at 360 minute time intervals to determine efficacy of each coating at the designated time interval. This time point was selected to ensure the products were allowed ample time to show a viral reduction. Control surfaces were left untreated with any antimicrobial coatings, inoculated with 20  $\mu$ L of MS2, allowed to dry, and then sampled at 360 minute time intervals.

Disinfectant wiping was applied to seat armrests, interior of bins, seat cushions (leather), seat tray tables, lavatory surfaces (faucet, counter, toilet seat lid) and galley counter surfaces. Test areas were first inoculated with 20  $\mu$ L of MS2, allowed to dry, then wiped with a cloth saturated with isopropyl alcohol 70% or Calla 1452, allowed to dwell for 10 minutes in accordance with EPA List-N guidelines and manufacturer's product label, and then finally sampled. The noted disinfectants represent two types based on chemical constitution – alcohol (isopropyl alcohol 70%) and quaternary ammonium compound (Calla 1452). Wiping of each disinfectant consisted of two basic methods – a heavy wipe and a light wipe. A heavy wipe involved a vigorous scrub of the surface in accordance with product labels and standard cleaning procedures, while a light wipe was performed in a quick and hastened manner intended to be a reduced-effort application. One additional test case introduced an isopropyl alcohol 70%, heavy wipe with a microfiber cloth to determine whether a microfiber cloth would contribute to viral reduction efficacy.

An electrostatic sprayer, ESS SC-EB, using the disinfectant Calla 1452 was applied to seat armrests, insides of bins, seat cushions (leather), and seat tray tables. Test areas were first inoculated with 20  $\mu$ L of MS2, allowed to dry, then sprayed, allowed to dwell for 10 minutes, and then finally sampled. Spray from the electrostatic sprayer was applied using two basic methods – a heavy spray and a light spray. A heavy spray was applied by passing the spray nozzle over a targeted surface three times back and forth over a 90-degree arc, while a light spray was applied by passing the spray nozzle once over a targeted surface over a 90-degree arc.

Ultraviolet light at 222 nm was applied to seat armrests, insides of bins, seat cushions (leather), and seat tray tables. These surfaces were first inoculated with 20  $\mu$ L of MS2, allowed to dry, then irradiated with an average of 960 mJ/cm<sup>2</sup> of energy dosage, and finally sampled. The average energy was dosed at 2" distance from each surface for 180 seconds.

MS2 remains relatively stable for up to 24 to 48 hours once applied so it was important to complete testing and return the samples to the University of Arizona for analysis immediately following conclusion of testing. All samples were placed in an ice cooler and shipped back to the University

of Arizona's WEST Center in Tucson, Arizona overnight for analysis. Samples were assayed and results provided within a few days after the samples were received.

#### University of Arizona Lab Testing

Additional testing was performed at the University of Arizona's Water & Energy Sustainable Technology (WEST) Center in Tucson, Arizona September to November 2020. This was done not only to corroborate and further validate treatment efficacy against MS2, but also to primarily determine treatment efficacy against the more representative human coronavirus HCoV-229E and novel human coronavirus SARS-CoV-2, which needed to be completed in controlled laboratory environments rated for Biological Safety Levels (BSL) 2 or 3.

Disinfectant wiping with a heavy wipe was performed with isopropyl alcohol 70% and Calla 1452 against MS2 and HCoV-229E. Testing was performed with four different surfaces provided by Boeing representing common aircraft interior materials – decorative laminate, seat fabric, foambacked seat leather, and thermoplastic threshold trim. Testing with isopropyl alcohol 70% against SARS-CoV-2 is ongoing.

Antimicrobials, Boeing P13 and P12 were tested against HCoV-229 and SARS-CoV-2 at various time intervals – 15 minutes, 30 minutes and 60 minutes in order to determine kill speeds. Testing was completed on armrest materials that were pre-applied with the Boeing polymers. Four additional third-party antimicrobials were tested against MS2 and HCoV-229E, mostly at time intervals of 60 minutes.

Ultraviolet light (222 nm) was tested in the laboratory against MS2 and HCoV-229E. Refer to Appendix, Photographs A11-A12. Testing was performed with four different surfaces provided by Boeing representing common aircraft interior materials – decorative laminate, seat fabric, foambacked seat leather, and thermoplastic threshold trim. These surfaces were irradiated with an average of 1,130 mJ/cm<sup>2</sup> against MS2 and 7 mJ/cm<sup>2</sup> against HCoV-229E. The average energy was applied at 2" distance from each surface for 240 seconds and 1.5 seconds against MS2 and HCoV-229E respectively.

Electrostatic sprayers using disinfectant Calla 1452 was tested against MS2 and HCoV-229E and applied to four different surfaces provided by Boeing representing common aircraft interior materials – decorative laminate, seat fabric, foam-backed seat leather, and thermoplastic threshold trim. Refer to Appendix, Photograph A13. Spray was applied through a light application, heavy application, and a heavy application followed by a cloth or microfiber wipe.

# <u>Results</u>

Results were obtained through a cytopathogenic effects (CPE) plaque assay process carried out by the University of Arizona. The MS2 assay process involves introducing the sampled MS2 to *Escherichia coli* bacteria, appropriate dilution of the resulting mixture, and addition of the mixture to a double agar medium. The presence of MS2 leads to lysis and destruction of the bacteria, which are visible as plaque clusters. These plaques are then counted and represent the amount of recovered virus, relative to a baseline control sample. The difference between viral recovery from the control and sample yields the viral reduction. This is typically expressed as a log-base 10 reduction value, which can be represented as a percentage reduction.

- 1 log<sub>10</sub> reduction = 90% reduction
- 2 log<sub>10</sub> reduction = 99% reduction
- 3 log<sub>10</sub> reduction = 99.9% reduction
- $4 \log_{10}$  reduction = 99.99% reduction
- $5 \log_{10}$  reduction = 99.999% reduction

For example, if there were 1,000,000 ( $10^6$  or 6 log\_{10}) viruses on a control surface, and a sample yielded a recovery of 100 ( $10^2$  or 2 log\_{10}) viruses observed through the assay process, the reduction would be represented as  $10^4$  or 4 log\_{10} or 99.99% reduction. The assay process for HCoV-229E and SARS-CoV-2 differs in that the recovered samples are placed on live animal cells and the destruction of these cells is observed over a period of time, typically five to seven days.

Table 1 below presents the results from the mockup and airplane testing against MS2. The rows represent specific disinfection treatments, and the columns represent the average log<sub>10</sub> reduction, average percentage reduction, and the standard deviation across the range of tested surfaces. The notes represent the surfaces tested for a given treatment, and in the case of antimicrobial coatings, the kill time at which the result is presented.

	Boeing	g Mockup	Boeing Airplane										
	n	MS2						MS2					
Treatment	Notes atment (Surfaces / Kill Time)		Std Dev	Avg Reduction (%)	Notes (Surfaces / Kill Time)	Avg Reductio n (Log10)	Std Dev	Avg Reduction (%)					
Disinfectant Wiping													
Wipe-70%IPA-Microfiber		-	-	-	$A_aB_aS_{ac}T_a$	3.08	0.85	99.92%					
Wipe-70%IPA-Heavy	$A_m B_m S_{mc} S_{mb} T_m W_m$	2.56	0.98	99.72%	$A_aG_aB_aL_{ac}S_{ac}L_{as}T_a$	3.05	1.01	99.91%					
Wipe-70%IPA-Light	$A_{m}B_{m}L_{mf}L_{mc}L_{ms}L_{mw}S_{mc}S_{mb}T_{m}W_{m}$	2.86	1.52	99.86%	$A_{a}L_{af}G_{a}B_{a}L_{ac}S_{ac}L_{as}T_{a}$	1.02	0.71	90.37%					
Wipe-Calla 1452 Heavy	$A_m B_m S_{mc} S_{mb} T_m W_m$	2.61	1.29	99.75%	$A_aB_aS_{ac}T_a$	2.80	0.59	99.84%					
Wipe-Calla 1452 Light	A <sub>m</sub> B <sub>m</sub> S <sub>mc</sub> T <sub>m</sub>	2.59	1.36	99.74%	$A_a B_a S_{ac} T_a$	1.52	0.58	96.98%					
Antimicrobials													
Antimic - Boeing P13		-	-	-	T <sub>a</sub> / 360 min	3.19	1.48	99.93%					
Antimic - Boeing P11		-	-	-	T <sub>a</sub> / 360 min	3.09	1.00	99.92%					
Antimic - Boeing P6	A <sub>m</sub> B <sub>m</sub> S <sub>mc</sub> S <sub>mb</sub> T <sub>m</sub> W <sub>m</sub> / 60 min	0.62	0.69	75.81%		-	-	-					
Antimic- Third-Party Product #1	$A_m B_m S_{mc} S_{mb} T_m W_m / 60 \min$	0.71	0.77	80.67%	T <sub>a</sub> / 360 min	0.47	0.36	65.78%					
Antimic - Third-Party Product #2	M <sub>1</sub> / 60 min	(0.26)	0.09	-81.08%		-	-	-					
Antimic - Third-Party Product #3	M <sub>2</sub> / 60 min	(0.17)	0.05	-48.77%		-	-	-					
Antimic - Third-Party Product #4		-	-	-	T <sub>a</sub> / 360 min	0.32	0.15	51.91%					
Antimic - Third-Party Product #5		-	-	-	T <sub>a</sub> / 360 min	0.20	0.28	36.28%					
Antimic - Third-Party Product #6	$A_m B_m S_{mc} S_{mb} T_m W_m / 60 \min$	0.86	1.55	86.27%		-	-	-					
Ultraviolet Light													
UV-222 nm - 1400 mJ/cm2	S <sub>c</sub> T <sub>m</sub>	2.77	0.86	99.83%		-	-	-					
UV-222 nm - 960 mJ/cm2		-	-	-	$A_a L_{ac} S_{ac} T_a$	2.40	0.71	99.60%					
Electrostatic Sprayer													
Spray-Calla 1452 - Heavy	$A_m B_m S_{mc} S_{mb} T_m W_m$	1.37	1.74	95.73%	$A_a B_a S_{ac} T_a$	0.29	0.31	49.13%					
Spray-Calla 1452 - Light	$A_m S_{mc} S_{mb} T_m W_m$	0.77	0.80	83.02%	$A_aB_aS_{ac}T_a$	0.09	0.22	19.21%					

	Table 1: Results from	Mockup and	d Airplane test	against MS2
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The surfaces tested during mockup testing are noted as follows:

- A<sub>m</sub>: Armrest
- B<sub>m</sub>: Bin latch
- L<sub>mf</sub>: Lavatory Faucet
- L<sub>mc</sub>: Lavatory Counter
- L<sub>ms</sub>: Lavatory Seat Lid
- L<sub>mw</sub>: Lavatory Waste Flap
- S<sub>mc</sub>: Seat Cushion
- S<sub>mb</sub>: Seat Back
- T<sub>m</sub>: Tray Table

The surfaces tested during airplane testing are noted as follows:

- A<sub>a</sub>: Armrest
- L<sub>af</sub>: Lav Faucet
- Ga: Galley Counter
- B<sub>a</sub>: Bin interior
- Lac: Lav Counter
- S<sub>ac</sub>: Seat Cushion
- Las: Lav Seat Lid
- T<sub>a</sub>: Tray Table

Table 2 below presents the results from laboratory testing at the University of Arizona against MS2, HCoV-229E and SARS-CoV-2. Ongoing testing at the time of this writing is highlighted in yellow. The rows represent specific disinfection treatments, and the columns represent the average log<sub>10</sub> reduction, average percentage reduction, and the standard deviation across the range of tested surfaces. The notes represent the surfaces tested for a given treatment, and in the case of antimicrobial coatings, the kill time at which the result is presented.

#### Table 2: Results from University of Arizona lab test against MS2, HCoV-229E and SARS-CoV-2

	U of A Lab				U of A Lab				U of A Lab			
	MS2				HCoV-229E				SARS-CoV-2			
Treatment	Notes (Surfaces / Kill Time)	Avg Reductio n (Log10)	Std Dev	Avg Reduction (%)	Notes (Surfaces / Kill Time)	Avg Reductio n (Log10)	Std Dev	Avg Reduction (%)	Notes (Surfaces / Kill Time)	Avg Reduction (Log10)	Std Dev	Avg Reduction (%)
Disinfectant Wiping												
Wipe-70%IPA-Heavy	DLFT	1.32	0.58	95.21%	DLFT	4.00	0.36	99.99%				
Wipe-Calla 1452 Heavy	DLFT	1.23	0.62	94.11%	DLFT	2.74	0.60	99.82%				
Antimicrobials												
									A / 15 min A / 30 min	2.22 3.57	-	99.39% 99.97%
Antimic - Boeing P13					A / 30 min	3.75	-	99.98%	A / 60 min	4.35	-	99.996%
Antimic - Boeing P12					A / 30 min	3.75	-	99.98%	A / 30 min	1.50	-	96.84%
Antimic- Third-Party Product #1												
Antimic - Third-Party Product #5					DLFT / 60 min	0.04	0.23	8.80%				
Antimic - Third-Party Product #6					DLFT / 60 min	3.58	0.21	99.97%				
Antimic - Third-Party Product #7	SU / 60 min	0.15	0.72	29.21%	SU/60min	1.13	0.52	92.59%				
Antimic - Third-Party Product #8	XP / 360 min	-0.04	0.32	-9.65%								
Ultraviolet Light												
UV-222 nm - 1130 mJ/cm2	DLFT	2.01	0.74	99.03%								
UV-222 nm - 7 mJ/cm2					DLFT	1.42	0.54	96.23%				
Electrostatic Sprayer												
Spray-Calla 1452 - Heavy+Wipe (MFB)	Т	2.65	-	99.78%								
Spray-Calla 1452 - Heavy+Wipe (Cloth)	DLFT	1.82	0.94	98.49%	DLFT	2.05	1.11	99.12%				
Spray-Calla 1452 - Heavy	DLFT	-0.17	0.12	-47.75%	DLFT	1.08	0.18	91.70%				
Spray-Calla 1452 - Light	DLFT	0.29	0.11	48.13%	DLFT	0.87	0.12	86.46%				

The surfaces tested during University of Arizona laboratory testing are noted as follows:

- D: Decorative Laminate
- L: Leather (foam-backed)
- F: Seat Fabric
- T: Threshold Trim (plastic)
- S: Stainless Steel
- U: Aluminum
- X: Leather
- P: Plastic
- A: Armrest

The following summarizes the results obtained from testing:

#### **Disinfectants**

- Disinfectant wiping with isopropyl alcohol 70% or Calla 1452 using a heavy wipe achieved greater than 2 log<sub>10</sub> (99%) or nearly 3 log<sub>10</sub> (99.9%) efficacy against MS2.
- Disinfecting using a heavy or light wipe yielded similar results (>99%) against MS2 during mockup testing, whereas heavy wiping (> 99%) outperformed light wiping (< 99%) against MS2 during airplane testing.
- Disinfectant heavy wiping in the laboratory against HCoV-229E achieved greater than 99.99% efficacy for isopropyl alcohol and close to or greater than 99.9% efficacy for Calla 1452. For all materials tested – decorative laminate, seat fabric, seat foam-backed leather and threshold trim – the seat fabric showed noticeably lower efficacy (slightly less than 99%) with Calla 1452.

# Antimicrobial Coatings

- Antimicrobial coatings tested during the mockup test (Boeing polymer P6 and four thirdparty coatings) were determined to be less effective (< 90%) against MS2. The results presented are shown for the 60 minute time interval. This time interval was selected to determine the speed and efficacy of these coatings, and to align with the EPA's performance requirements of a minimum 3 log reduction within one to two hours in support of registration of antimicrobial coatings<sup>10</sup>. Other time points help determine the kill speed, allowing for further comparisons between products.
- Of the antimicrobial coatings tested during the airplane test (Boeing polymers P11, P13 and three third-party coatings), the Boeing polymers P11 and P13 showed greater than 99.9% efficacy. The results presented are shown for the 360 min time interval.
- Boeing antimicrobial polymers P12 and P13 achieved nearly 99.99% efficacy against HCoV-229E within 30 minutes. The third-party coatings achieved mixed results, depending on the product, with less than 90%, greater than 90%, and greater than 99.9% efficacy against HCoV-229E in 60 minutes.
- The antimicrobial coating, Boeing polymer P13, showed nearly 99.99% reduction in 30 min and nearly 99.999% in 60 min against SARS-CoV-2.

# Ultraviolet Light (222 nm)

- 222 nm ultraviolet light applied against MS2 at average energy levels of 960 mJ/cm<sup>2</sup>, 1130 mJ/cm<sup>2</sup>, and 1400 mJ/cm<sup>2</sup> on various surfaces in the mockup, aircraft and laboratory settings resulted in greater than 99% efficacy.
- 222 nm ultraviolet light applied against HCoV-229E at an average energy level of 7 mJ/cm<sup>2</sup> on various surfaces in a laboratory setting resulted in a viral reduction less than 99%. Based on this test data, a log linear analysis suggests that greater than 99.9% efficacy can be achieved with 15 mJ/cm<sup>2</sup> energy.

# Electrostatic Sprayer

- Electrostatic spray with Calla 1452 in the mockup and airplane against MS2 generally resulted in less than 90% efficacy with the heavy and light spray.
- Electrostatic spray with Calla 1452 in the laboratory against MS2 resulted in less than 90% efficacy with the heavy and light spray. Electrostatic spray with Calla 1452 followed by a cloth or microfiber wipe against MS2 resulted in nearly 99% or greater efficacy.
- Electrostatic spray with Calla 1452 against HCoV-229E resulted in an efficacy less than 90% for light spray, greater than 90% for heavy spray, and greater than 99% for heavy spray followed by a cloth wipe.

# **Conclusions**

The following represents the conclusions drawn from the testing noted in this paper:

<u>General</u>

- The airplane environment can be effectively disinfected with appropriate methods.
- Variations in results are seen with treatment, application and to some degree materials.
- Treatments were generally highly effective across a wide range of representative high touch point surfaces in an aircraft interior.

- The test results show that these technologies and applications are highly effective in eliminating key viruses on representative aircraft surfaces.
- While MS2 and HCoV-229E are similar to SARS-CoV-2, additional data against SARS-CoV-2 will confirm the efficacy of these treatments further and draw even stronger conclusions.

# **Disinfectants**

- Disinfectant wiping is shown to be highly effective with greater than 4 log<sub>10</sub> (> 99.99%) reduction against HCoV-229E.
- Disinfectants with alcohol composition (isopropyl alcohol 70%) or quaternary ammonium compounds (Calla 1452) performed equally well with both being highly effective against HCoV-229E.
- Wiping, particularly with disinfectants is shown to be a highly effective action for disinfection. Heavy wiping in accordance with product labels was consistently effective, while light wiping showed a mix of similar efficacy or slightly lesser efficacy. While light wiping may result in equally effective results, it is advisable to use a heavy wipe per standard prescribed methods.

# Antimicrobial Coatings

 Several antimicrobial coatings show close to 4 log<sub>10</sub> (99.99%) reduction against HCoV-229 within 30 minutes.

Ultraviolet Light (222 nm)

- Ultraviolet light at 222 nm was a highly effective treatment against MS2 with between 2 log<sub>10</sub> (99%) and 3 log<sub>10</sub> (99.9%) reduction achieved at energy levels between 960 and 1,400 mJ/cm<sup>2</sup>.
- Ultraviolet light at 222 nm against HCoV-229E with a dosage of 7 mJ/cm<sup>2</sup> yielded test results of less than 99% reduction. Based on this test data, a log linear analysis suggests that greater than 99.9% efficacy can be achieved with 15 mJ/cm<sup>2</sup> energy.
- A greater than 99.9% reduction of MS2 or HCoV-229E can be achieved with the appropriate energy dose.

Electrostatic Sprayer

• Electrostatic sprayer application using chemical disinfectant Calla 1452, followed by a quick cloth wipe showed greater than 2 log<sub>10</sub> (> 99%) reduction.

# Limitations and Future Research

While the Clean Airplane Program collected a wide range of test data with various viruses, environments (mockup, airplane and laboratory), and treatments on commercial aircraft surfaces, the limitations of this testing and opportunities for future research are outlined as follows:

- SARS-CoV-2 test data At the time of this writing, test data was gathered largely for MS2 and HCoV-229, with ongoing testing being conducted against SARS-CoV-2. While MS2 and HCoV-229E data are believed to be leading indicators of performance against SARS-CoV-2, it is necessary to continue gathering data against SARS-CoV-2 for completeness.
- Materials Materials used in testing represent a wide range of materials prevalent in commercial aircraft cabins. While much of the data suggests that the treatments can

generally be applied to a wide range of commercial aircraft materials, some degree of material dependency was observed and expected to occur. This was observed in some tests concerning porous seat fabrics. Additional testing focused on a wider range of materials or a more rigorous review of materials would be useful.

- Environmental effects Temperature and humidity are believed to have an effect on the viability and stability of viruses. While temperature and humidity mostly represented prevailing conditions during the mockup and airplane tests, and relative humidity was targeted at 50% during laboratory tests, these parameters were not rigorously controlled. Additional testing with an emphasis on temperature and humidity conditions could help determine the precise effects from these conditions.
- Antimicrobial Coatings Results for antimicrobial coatings represent the efficacy of an evenly coated surface, and do not address the persistence or durability of these coatings. Additional testing could review the efficacy of these coatings subject to mechanical abrasion, wear, and time.
- Additional Testing Some treatments such as UV and Electrostatic Sprayers were not tested against SARS-CoV-2 due to limitations imposed by protocols associated with BSL-3 lab environments. Such testing could be included as future research.

# <u>Appendix</u>



A1 – Photograph – 787 Mockup Space, Forward Zone, Aircraft Integration Center, Everett, Washington



A2 – Photograph – Sample areas with identification labels marked seat cushion in mockup



A3 – Photograph – Sample areas with identification labels marked on tray table and window buttons in mockup



A4 – Photograph – 737 aircraft with representative interior, Boeing Field, Seattle, Washington



A5 – Figure – 737 Layout of Passenger Arrangement (LOPA) plan showing aircraft locations designated for each disinfection treatment category



A6 – Photograph – Sample areas with identification labels marked on aircraft tray tables and bin interiors, Boeing Field, Seattle, Washington



A7 – Photograph – Sample areas with identification labels marked on aircraft galley counter, Boeing Field, Seattle, Washington



A8 – Photograph – Sample areas with identification labels marked on aircraft lavatory surfaces, Boeing Field, Seattle, Washington



A9 – Photograph – Application of ultraviolet light on aircraft lavatory and seat surfaces, Boeing Field, Seattle, Washington



A10 – Photograph – Application of disinfectant using an electrostatic sprayer on interior surfaces, Boeing Field, Seattle, Washington



A11 – Photograph – Laboratory room setup with hood showing ultraviolet light device, University of Arizona WEST Center, Tucson, Arizona



A12 – Photograph – Application of ultraviolet light on test samples, University of Arizona WEST Center, Tucson, Arizona



A13 – Photograph – Application of disinfectant using an electrostatic sprayer on a test sample placed in a hood, University of Arizona WEST Center, Tucson, Arizona

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