# The AeroClenz™ System

## Efficacious and Safe Real-Time Disinfection for Aircraft Cabins, Galleys, and Lavatories.

**Prepared by**

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# INTRODUCTION

The recent pandemic has drastically and negatively affected passenger confidence and willingness to choose air travel. The AeroClenz™ System offers the ability to differentiate equipment, facilities, and services by offering the most advanced and effective airborne disinfection technology available while ensuring optimal health and safety related to both UV-C disinfection and minimized exposure to pathogens (including viruses, bacteria, spores, and fungi). **The AeroClenz™ System is more effective at reducing the risk of infection from airborne pathogens than any other method available in aircraft cabins, including enhanced ventilation, ionization, episodic cleaning and cloth, surgical, KN-95 or N-95 masks.** The AeroClenz™ System uses dual-beam continuous UV-C and targeted UV-C with triple-redundant sensor gating to safely disinfect cabin air in both occupied and unoccupied spaces. The addition of this state-of-the-art capability to aircraft will provide value and confidence to passengers and reduce the need for costly and time-consuming disinfection procedures. The AeroClenz™ System is designed to effectively inactivate (or kill) airborne pathogens in aircraft cabins with the capability of future application to jetways, lounges and waiting areas. Devices are custom configured for each installation and use UV-C light to actively inactivate pathogens at their point of origin (e.g., exhalation from an infectious passenger).

## Passenger Perceptions

Hesitancy to use air travel in recent times due to viral pathogens, including SARS-CoV-2, which causes COVID-19, stems from fears of becoming ill, causing infection, illness or death to others or family members and financial loss due to loss of employment or inability to work [1], [2]. It is now acutely understood that national and international spread of respiratory viruses like SARS-CoV- 2 (Influenza H1N1, SARS and common cold viruses, pneumonia, tuberculosis, measles, and other diseases) are potentially facilitated by air travel. It was recently determined that 66% of variance in willingness to fly for either pleasure or business travel was attributable to the perceived threat of exposure to SARS-CoV-2 [3]. As a result, year-on-year air travel had decreased by 70% by the first quarter of 2020 and industry-wide revenue passenger kilometers (RPKs) fell by the same [4]. While the airline industry has been resilient in overcoming other challenges in passenger confidence in safety, including events related to terrorism, fundamental adaptations will be required to mitigate the newly appreciated threat of viral pathogens for the industry to enjoy continued success. With sluggish management of COVID-19 globally, there was prolonged pandemic status, and the persistent rise of new and more transmissible variants may have extended the recovery of commercial air travel. However, effective and safe disinfection technologies for aircraft promise to provide a head-start in the recovery of passenger confidence and revenue-generating passenger seat miles to fleets that choose to utilize them.

## Risk of Exposure to Airborne Pathogens in Aircraft

With the prominence of the airborne route of transmission of SARS-CoV-2 and other respiratory viruses now being broadly recognized, enclosed spaces, particularly those housing multiple individuals in tight quarters obviously carry increased risk of airborne transmission. Accordingly, virtually all “super spreader events” have occurred in enclosed spaces [5][6]. SARS-CoV-2 was recently detected in the wastewater of 81% of long-haul flights at JFK International Airport [7]. In the air travel industry, several examples of transmission events involving multiple passengers have been documented on flights [8]–[10]. It is clear that risk is greater on flights where rigid masking is not implemented [10]; however, as of April 2023 most airlines have dropped any masking requirements. Furthermore, most masks in use are cloth masks, which are permeable to up to 97% of aerosol particles, or surgical masks which are permeable to up to 44% of aerosol particles, when used correctly [11], [12]. Many users do not cover their nose to provide a sufficient seal, and improper sealing of these masks can further reduce filtration by 60% [12]. The risk of pathogen transmission on flights does not end with COVID-19. Metabiota, a company that tracks infectious disease risk, estimates a 47–57% chance of a pandemic at least as deadly as COVID-19 in the next 25 years [13].

According to epidemiological data from the CDC [14]–[18], flight statistics from the FAA [19], and analysis protocols and formulas from peer-reviewed scientific journal articles, we computed the following estimates for the impact of SARS-CoV-2 and Influenza A on board aircraft:

- **10,000 annual deaths and 3,000,000 infections due to transmission of SARS-CoV-2 and Influenza A combined aboard US commercial aircraft.**
- **Up to 8,000 of those annual deaths might be avoided by supplementing the aircraft ventilation with UV-C air disinfection.**
- **$200 B annual economic burden due to transmission of SARS-CoV-2 and Influenza A aboard aircraft during the COVID-19 pandemic.**

## Current Technologies and their Limitations

Previous and current technological strategies for mitigating the infection risk from pathogens on aircraft have included HEPA filtration, ionization and surface decontamination. High-efficiency particulate absorbing (HEPA) filters are capable of filtering viruses of submicron sizes, including SARS-CoV-2 [20]; however, there are shortcomings of this technology in the context of aircraft cabins, and not all aircraft use it. The airflow patterns created by aircraft ventilation systems create pockets of air that are uncirculated, particularly within the seating spaces and lower part of the aisles. Even in larger aircraft with HEPA ventilation systems, increased transmission potential via airborne routes remain for seats that are adjacent to infectious sources [21], [22]. Computer modeling based on experimental data and actual infection transmission showed that these adjacent seating positions, including those of passengers in rows ahead and behind an infectious source, are at risk of infection via airborne flow in the overhead space [22]. These studies provide strong evidence for airborne transmission of SARS-CoV-2 on flights with HEPA ventilation systems. In addition, airborne viruses must be circulated through the cabin to the filters in order to be neutralized by filtration systems as opposed to the direct inactivation of pathogens at the point of origin without the flow of air, as provided by the The AeroClenz™ System. Further, HEPA filters have decreased ability to neutralize particles with a diameter of around 0.15 µm, which is within the broad range of particle sizes that harbor SARS-CoV-2 [23].

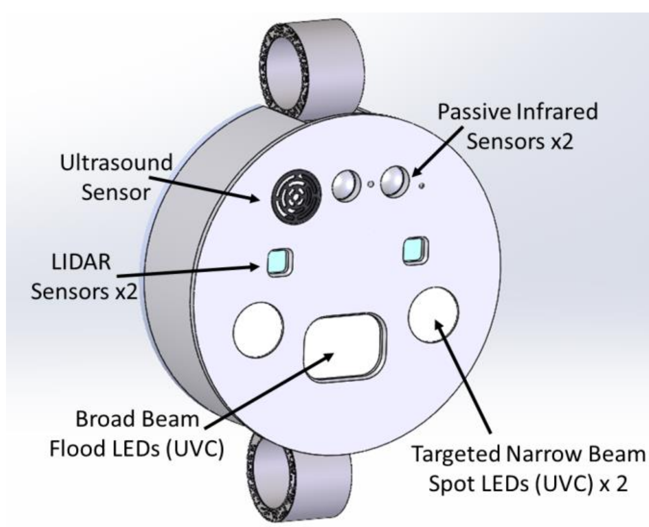
Ionization is another technology that has been explored for inactivation or neutralization of airborne pathogens on aircraft. Needle point bipolar ionization (NPBI) is the only ionizing technology approved for use in certain types of aircraft and has been used in craft of a similar size as Boeing Business Jets [24]. With this technology, water in the air is converted to reactive oxygen compounds that can remove or neutralize hydrogen on the surface of pathogens to inactivate them. Inactivation rates for ionization have been found to be lower than those of HEPA filtration or UV-C methods and require longer exposure times on the order of hours [24]. In a study by the University of Arizona in partnership with Boeing, air ionization by NPBI with an exposure time of 60 minutes was found to inactivate only 66.7% of Coronavirus 229E, a surrogate for SARS-CoV-2, which is well below standards for significant antimicrobial efficiency [24]. Boeing's testing efforts determined that existing ionization systems were unable to achieve sufficient antimicrobial effectiveness for aircraft [24]. A class-action suit has been proposed against a company making NPBI equipment because of failure to effectively disinfect as advertised in real-world settings [25]. Regarding safety, ozone, which may be created by ionization technology, can be hazardous to humans with extended exposure and can result in inflammatory responses in people with asthma [26] and respiratory symptoms in asthmatic children, even at low concentrations and exposure times [27].

Surface decontamination has been implemented in the air travel industry on aircraft and in airport facilities for the majority of the duration of the pandemic. However, these practices only apply to surfaces, such as tray tables, handles and seats and cannot effectively curb airborne transmission. Only in incidences where a surface was contaminated by sneezing or coughing and then touched by someone else is transmission by surface contact a significant but still remote possibility [28]. While surface decontamination may decrease the transmission of some pathogens, risk of surface transmission of SARS-CoV-2 and similar respiratory viruses is considered to be very low [28], leaving the airborne route as the most prevalent important mode of transmission by far.

The only technology currently in broad use for mitigation of airborne pathogen exposure on aircraft, HEPA filtration, has not alleviated unfavorable passenger perception of disease risk. This technology has also been broadly in use since well before the current pandemic. While physical distancing on aircraft may reduce risk of exposure, this option is not compatible with adequate revenue-seat occupancy. Masking and social distancing are disagreeable to passengers and financially unviable to the air travel industry. These factors create a continuing need for effective pathogen disinfection technologies, exemplified by The AeroClenz™ System, to minimize disease risk on flights and assure passengers of the safety of air travel.

## THE AEROCLENZ™ SYSTEM

To address the currently unmet need and drastically reduce pathogen exposure risk onboard aircraft, we have developed The AeroClenz™ System. The platform employs UV-C LED technology at its core to provide safe and highly effective pathogen disinfection without the limitations imposed by existing technology. The AeroClenz™ System is comprised of a family of related products for targeted areas of the aircraft, including the lavatory, aisles, and full cabin. Each product is adapted to its use case, including intensity and coverage, and paired with appropriate occupancy sensors. The



AeroClenz™ System is effective and doesn't require compliance from passengers to be effective.

## UV-C LED Technology

The utility of ultraviolet (UV) light for inactivating microbes has been established for over 100 years. Mercury-vapor arc lamps emitting UV light with a maximum intensity at a wavelength of 254 nm is most commonly used, followed by the more recent implementation of xenon lamps [29]. These technologies are both effective at inactivating viruses and bacteria, but emit a broad spectrum of UV light wavelengths, some of which can cause DNA damage and irritation of the skin and eyes. Additionally, the UV output of mercury and xenon lamps are too great to be allowed for direct exposure to people, meaning that those light sources must be shielded inside the HVAC duct or another enclosure and therefore depend on the unfavorable airflow patterns encountered in aircraft ventilation. In addition to the obvious health risks of mercury vapor, these lamps also require additional filters to restrict output to the proper wavelengths to avoid the above-stated potential for damage and irritation.

Recent technological advances, however, have enabled the production of UV-C light via light-emitting diodes (LEDs). In contrast to mercury vapor and xenon lamps, LEDs employ semiconductors (as with computer chips but using AlGaN material instead of silicon as the base material) to generate targeted wavelengths [30]. These UV-C LEDs inherently produce a narrower bandwidth that is designed to reside within the UVC band, where any dangers of human exposure are minimal. Further, they are efficient, compact, and lower cost than previous UV-C technologies.

## Virucidal Activity of 265 nm Monochromatic UV-C

Light in the UV-C wavelength range has been recently applied to the inactivation of airborne human coronaviruses. The inactivating potential of UV-C light is based on damage to the RNA or DNA of viruses and bacteria and depends on the UV irradiance (UV energy per surface area) [31]. It was recently demonstrated that UV-C light at 222 nm that is well within regulatory limits for an 8-hour exposure of occupied spaces inactivated 90% of airborne human coronaviruses in 8 minutes and 99.9% in 25 minutes [29]. In a more recent study, room disinfection with 265 nm UV-C light, which is the same wavelength as used in the Aeroclenz™ System, inactivated over 99.99% of airborne SARS-CoV-2 within 30 minutes [32]. Aerosolized human coronaviruses have been shown to be particularly susceptible to UV-C inactivation compared to other viruses (MS2 bacteriophage and adenovirus) [33]. Additionally, UV-C light is known to be effective against a variety of viral pathogens, including Influenza viruses, cold viruses, hepatitis viruses and HIV; and bacterial pathogens, including M. tuberculosis, E. coli, C. diff and Salmonella species [34]–[36]. Although these studies were performed at various UV-C wavelengths from 222 nm to about 280 nm, sensitivities of coronaviruses were found to be similar across all wavelengths of UV-C from 222 to 282 nm [30].

The AeroClenz™ System components for disinfecting aisles when not occupied provide enough UV-C output to inactivate 90% of airborne SARS-CoV-2 in around 2 minutes, and those for lavatories provide enough to inactivate the virus at this level in approximately 1 minute [37]. The disinfection potency of UV-C as described above is at least as high as that of the most effective technologic mitigation system currently employed in aircraft cabins, HEPA filtration systems. In fact, we have calculated that the Aeroclenz™ System can inactivate SARS-CoV-2 in the air at a 3 to 5 times faster rate than a typical aircraft cabin ventilation system operating at 30 air changes per hour. Unlike air circulation and filtration systems, the AeroClenz™

System can inactivate airborne viruses at the site where they are exhaled by passengers and crew rather than transporting them through the cabin and trapping them in a remote filter. Relevant spaces, including overhead space and aisle space, can be effectively reached and disinfected by UV-C light. UV-C is also capable of inactivating pathogens that are both airborne AND on surfaces unlike HEPA, ionization or surface decontamination.

## UV-C Safety and Exposure Limits

It is known that certain wavelengths of UV light carry risk of skin cancer and erythema (sunburn) because of alteration of DNA directly or by creation of reactive oxygen species [26]. This effect of UV irradiation, however, requires exposure of the internal (basal dermis) layers of the skin containing live cells with actively functioning and replicating DNA [38], [39]. Unlike other wavelengths of UV, UV-C does not penetrate the outer epidermal layers, consequently not reaching susceptible DNA in skin cells. UV-C with a wavelength of 265 nm, as is used by AeroClenz™ System technology, approaches the shallowest penetration of skin within the UV spectrum, only reaching the outer cornified and stratified epithelium, tissue that is not susceptible to DNA damage or risk of carcinogenesis [40]. In comparisons of DNA damage to sensitive skin from UV-C versus sunlight at a UV index of 4, UV-C (222 nm) was found to require thousands to tens of thousands of hours of exposure to cause the same effect on DNA as 10 minutes of sun exposure [41]. This study concluded that even long-term exposure to UV-C is unlikely to increase skin cancer risk. Therefore, health risks associated with UV-C are predominantly limited to the potential for irritation and inflammation (erythema) of the conjunctiva of eyes and sensitive skin at higher doses and if exposure limits are exceeded [42], [43]. The new monochromatic LED technology utilized by The AeroClenz™ System is limited to a narrow bandwidth of UV light that excludes the more damaging UV-B wavelengths unlike mercury lamp technology. Further, the intensity of the UV-C light is limited to levels that are sufficient for disinfection but low enough to minimize any safety concerns. Considering these relatively mild potential adverse erythema effects, 8 full hours of exposure to the range of UV-C light emitted by the AeroClenz™ System is equivalent to only about 5 minutes of sun exposure [37]. In actual aircraft usage, human exposure to the AeroClenz™ System-emitted light will be for a significantly shorter period of time, if at all.

Exposure guidelines have been long established and published for exposure to artificial UV-C light by the International Electrotechnical Commission (IEC), International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the International Organization for Standardization (ISO). These standards establish exposure limits (EL) for a broad spectrum of wavelengths of light, including UV, visible light and infrared, each carrying some health risk if exposure is high enough. UV light ELs "represent conditions under which it is expected that nearly all individuals may be repeatedly exposed without acute adverse effects and, based upon best available evidence, without noticeable risk of delayed effects" [44]. IEC and ICNIRP limits for exposure to UV light at 265 nm, as implemented by The AeroClenz™ System, within 8 hours have been set at 37 Joules/meter$^2$ [44], [45]. As described above, doses of UV-C light that are well under this exposure limit (20 Joules/meter$^2$) have been shown to be highly effective (99.9% inactivating within minutes) [29]. As described in detail below, The AeroClenz™ System technology adheres to these exposure limits within occupied areas of aircraft cabins while exploiting higher exposure levels with greater disinfection efficacy in unoccupied areas using precise and sensitive gating technology to ensure passenger safety.

## Occupancy Sensors (Safety Redundancy)

The emitted UVC light of the AeroClenz™ System is designed for maximal safety by constraining the intensity and wavelength. For additional safety redundancy, however, we have combined the UV-C output with three types of sensors, LIDAR, PIR, and ultrasound for detecting human occupancy in the lavatories and aisles, and immediately disabling UV-C light output upon detection. Both LIDAR and PIR sensors are optical-based sensors but use very different methods for detection, thus providing greater detection sensitivity, range, and accuracy, while ultrasound sensing provides a non-optical, independent method for greater diversity of people detection. Two LIDAR and PIR sensors are used on each device, in addition to the ultrasound sensor, thus providing further redundancy for additional protection. Future versions of the system may also include low-power mmWave technology (as a form of short-distance radar) to provide yet another independent method for occupancy detection.

### *LIDAR*

LIDAR, which stands for Light Detection and Ranging, is a sensing method that uses a beam of light (typically infrared) that is steered across a scene. The narrow beam reflects off of any objects, and the time it takes for the light to return back to the sensor is measured for each location of the beam. As the speed of light is a constant value in air, the measured time can be used to determine the distance to all objects within the field of view, resulting in a 3D map of the space. When used within the AeroClenz™ System, the LIDAR takes an initial baseline measurement, e.g., of an empty lavatory, then continually takes new measurements and compares them against the baseline for any differences. These differences are then used to identify the presence of a human and send an appropriate control signal to disable the UV-C light.

### *PIR*

PIR sensors, which stands for Passive Infrared sensors, do not emit any light, but instead passively detect the presence of light at certain wavelengths of infrared emitted by humans and animals due to their warmth. More specifically, PIR sensors detect a change in the infrared light as the source moves across the field of view, leading to differences in measured light on each side of the sensor. These sensors are thus used as the most common form of motion detectors.

### *ULTRASOUND*

In addition to the two optical sensor types described above, The AeroClenz™ System also uses ultrasound sensors to provide occupancy detection using a wholly independent method, thus providing greater versatility and redundancy of any unusual circumstances, though unlikely, that prevent the optical sensors from detecting the presence of humans in the targeted area. Ultrasound sensors emit high-frequency acoustic signals (above the range of human hearing) at safe low-levels of intensity, that are directed toward a target region. Just as with LIDAR the signals reflect off of objects in the scene and return to the sensor, which records the time-of-flight information, thereby providing distance information. When a person enters the region, the travel time of the ultrasonic beam changes dramatically, readily indicating their presence. While imaging or mapping, like with LIDAR, is also possible with certain ultrasound sensors via beam steering or using sensor arrays, the sensors used with the The AeroClenz™ System do not need this functionality in order to detect occupancy. Thus, a single (non-arrayed) sensor is employed here.

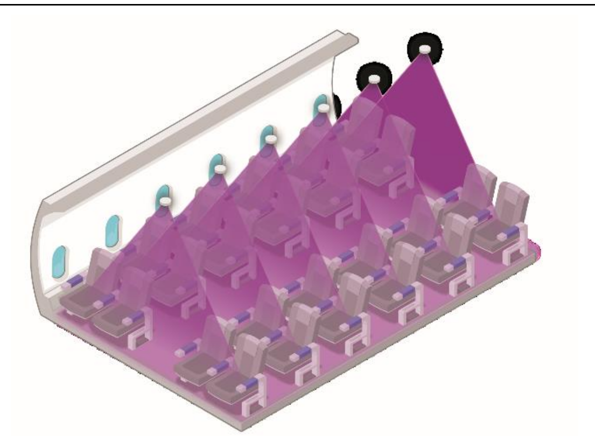
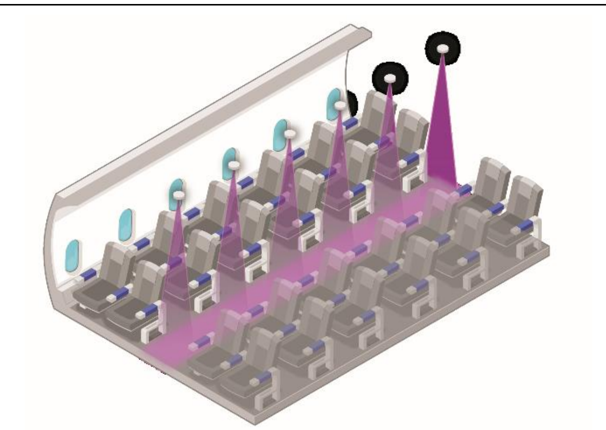
### *MMWAVE*

The AeroClenz™ team is now implementing millimeter wave (mmWave) technology as an additional sensor type for future generations of the system. mmWave technology is a form of radar (in this application using low power signals) and operates at high frequencies in the range of 30 to 300 GHz, which ranges between 1 and 10 millimeters in wavelength, allowing for highly precise measurements. By placing mmWave sensors throughout the cabin, the system can detect the presence of people and track their movements in real-time.

## The AeroClenz™ System Line of Products

The AeroClenz™ System, as first mentioned above, comprises a suite of related products to cover the range of use cases within the aircraft. Currently, three sensor-gated products are offered: one designed for the lavatory, one for the galley, and one targeted for use in the aisles. These all utilize the sensors described above to disable output immediately upon occupancy detection. A fourth product is offered for general use in the cabin and is designed to operate at lower intensities for continuous operation in the presence of humans.

As evidenced by the UV-C safety and exposure data above, the LED monochromatic source of UV-C light at 265 nm maximizes both the safety of exposure within the limits described and efficacy of inactivating airborne pathogens. The AeroClenz™ System consists of custom-installed devices that irradiate these targeted regions of aircraft exploiting 365DisInFx™ LPU technology, the first UL Certified direct LED UV-C luminaire for occupied spaces. The system leverages an advanced two-tier sensor fusion suite to ensure no over-exposure to cabin occupants using a combination of continuous and targeted disinfection.

|  |  |
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| **CONTINUOUS-CLEAN ENGINE**<br>• Full-cabin illumination<br>• Calculated for 24-hour eye/skin safe dose<br>• Advanced two-tier sensor fusion suite ensures no over exposure to cabin occupants can occur | **AISLE-SCRUB ENGINE**<br>• Narrow beam exposure<br>• 90% pathogen inactivation in < 3 minutes<br>• Intelligent sensors detect occupancy and control illumination |

The AeroClenz™ System products that target the cabin incorporate two distinct UV-C LED systems to efficaciously disinfect cabin air at UV-C doses to occupants that are below the allowed exposure limits. The first is a continuous broad-beam irradiation of passenger-occupied spaces in seating areas with energy output that remains below the 8-hour exposure limits for humans as set forth by IEC, ICNIRP and ISO as described above. This is known in the industry as DIBEL (Direct Irradiation Below Exposure Limits). The continuous broad-beam lamps disinfect air above passenger seats where airborne pathogens are most likely to pass between adjacent passengers within rows and in the rows behind and in front of infectious sources. The second is an occupancy-gated, narrow-beam source targeted into the aisle between seats that provides higher levels of disinfection above human exposure limits but does so using a triple-redundant sensor system to ensure passenger safety by disabling the light source well in advance of passenger occupancy of specific aisle space. This sensor system detects passenger occupancy well outside the UV-C beam by incorporating passive infrared, ultrasound, and LIDAR time-of-flight technology. Thus, airborne pathogens in the aisle space from floor to ceiling are quickly and effectively inactivated when that specific section of aisle space is unoccupied by passengers or crew.

## Value Proposition

By supplementing the aircraft ventilation with UV radiation, up to approximately 8,000 of the estimated 10,000 ongoing annual US deaths on board aircraft due to Influenza A and COVID-19 combined can be avoided, resulting in a savings of up to approximately $160 billion of the estimated $200 billion total economic burden.

The direct medical costs due to the 10,000 annual deaths due to transmission of SARS-CoV-2 and Influenza A aboard aircraft amounts to $6.4B per year at the present run rate from April '22 through March '23.

Improving passenger confidence has become increasingly critical for maximizing revenue for the air travel industry since the COVID-19 pandemic, which cost the industry tens of billions of dollars. Given the estimated cost of fleet-wide installation of the AeroClenz™ System at $1 per passenger ticket for one year, only a 1% improvement in passenger confidence translates to reimbursement for the installation cost, and a 20% improvement would increase passenger revenue by $14.66 billion over the installation cost. Aeroclenz™ aims to maximize passenger confidence, safety and revenue-generating seat miles with effective, real-time UV-C disinfection that requires no passenger compliance or manual administration.

# SUMMARY

UV-C irradiation is a highly effective and safe means of inactivating airborne viruses and other pathogens in enclosed spaces, including aircraft cabins. The safety of artificial germicidal UV-C light sources is well established, particularly within exposure limits set forth by international governing agencies. The dual-beam continuous and targeted technology and triple-redundant occupancy sensing technology employed by The AeroClenz™ System further enhances the safety of this system for use in occupied aircraft cabins. The virucidal efficacy of the The AeroClenz™ System is more effective than masks, and the combination of these systems has the potential to significantly decrease transmission of airborne pathogens in aircraft cabins. In addition, UV-C disinfection can overcome the airflow and time limitations of filtration systems and the compliance issues with masks. Assurance of safety from technologic and pathogenic sources can greatly improve in-flight experience, passenger perception of risk, willingness to fly and ultimately, revenues in the air travel industry.

## About the Authors

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Dr. Michael James is a scientist, entrepreneur and consultant to both academic researchers and the biotechnology industry. Dr. James earned his doctorate in Microbiology from the University of Iowa and was trained in the study of viral oncogenesis, virology, immunology and cancer cell/molecular biology there and at Washington University in St. Louis. During his 10 year tenure as faculty in the Pharmacology/Toxicology and Surgery departments at Medical College of Wisconsin, discoveries made in his laboratory led to his invention of experimental biologic drugs for the treatment of cancer. Dr. James has founded and led multiple startup companies to develop anticancer therapeutics, technologic advances in research tools and anti-viral nanoparticles for which he has received federal and international recognition and funding. He continues to contribute to the advancement of knowledge and technologies to mitigate some of the world's most formidable biologic challenges, including the respiratory viral pandemic and intractable, therapy-resistant cancers. Dr. James can be contacted at mjames118@hotmail.com.

### Stephen Horowitz, PhD

Dr. Stephen Horowitz is a technical executive with over 20 years of engineering and R&D experience in MEMS-based sensors and instrumentation, optics, acoustics, and microfabrication. In 2020, Dr. Horowitz founded Satori Scientific to provide technical and proposal writing services, along with targeted R&D consulting. He is also currently the CTO of Switching Battery, Inc, a developer of next generation energy transformation products. From 2014 through 2020, Steve was president of IC2, a developer and manufacturer of precision sensors and instrumentation for the aerospace industry. Prior to IC2, Steve spent 6 years as program manager and lead engineer for micro and nano systems research at Ducommun Miltec, later acquired by General Atomics. Before Miltec, Steve worked as a Research Scientist at Taitech, Inc., developing optical-based sensors for aeroacoustic applications. Steve is the author of 35+ publications and 3 patents related to sensors, acoustic and mechanical energy harvesting and technology for aircraft noise control. Steve received his PhD in 2005 in Electrical Engineering from the University of Florida. Dr. Horowitz can be reached at steve@satoriscientific.com.

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