Fighting the spread of pathogens in passenger aircraft cabins: an approach using computer simulations

Presented by

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Ansys

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Ansys Inc, San Jose (2018 -) – Technical Manager – ML/AI in Simulation, Digital Twin for IoT, Fluid Mechanics, Gas Turbine Design.

Adjunct Faculty, Santa Clara University

GE Global Research Center, Niskayuna - CFD, turbo-machinery, Digital Twin, turbulence modeling, high performance computing

Penn State University - MS & PhD - Aero-acoustics

IIT Kanpur - B. Tech - Experimental Fluid Mechanics

AIAA
- Lifetime Senior Member
- Applied Aerodynamics Technical Committee member
- Honors & Awards Director, AIAA San Francisco Section
- Presenter, AIAA LA-LV Section

A Leader in the Simulation Market for 50 Years

~2X THE SIZE OF OUR NEAREST COMPETITOR

(CIMdata June 2020 Report)*

#1 IN SIMULATION

FOCUSED

SIMULATION IS ALL WE DO

PROVEN

MEMBER OF PRESTIGIOUS

STANDARD & POOR'S

Nasdaq 100 Index

$26B market capitalization

(as of November 2, 2020)

COMMITTED

OVERALL CUSTOMER SATISFACTION GLOBALLY (2019): 85.9%

CAPABLE

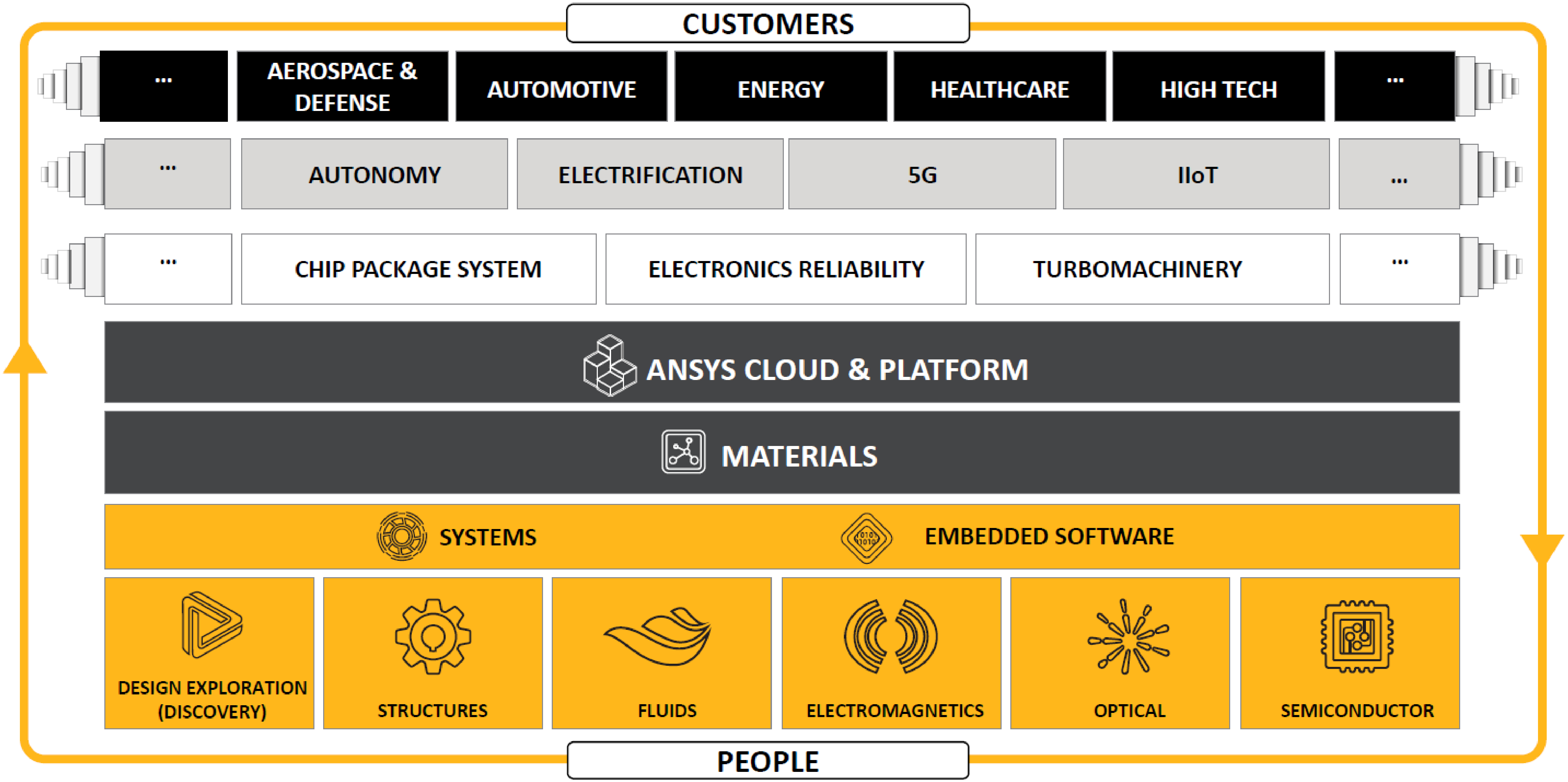
4,500 EMPLOYEES GLOBALLY

85 ANSYS OFFICES

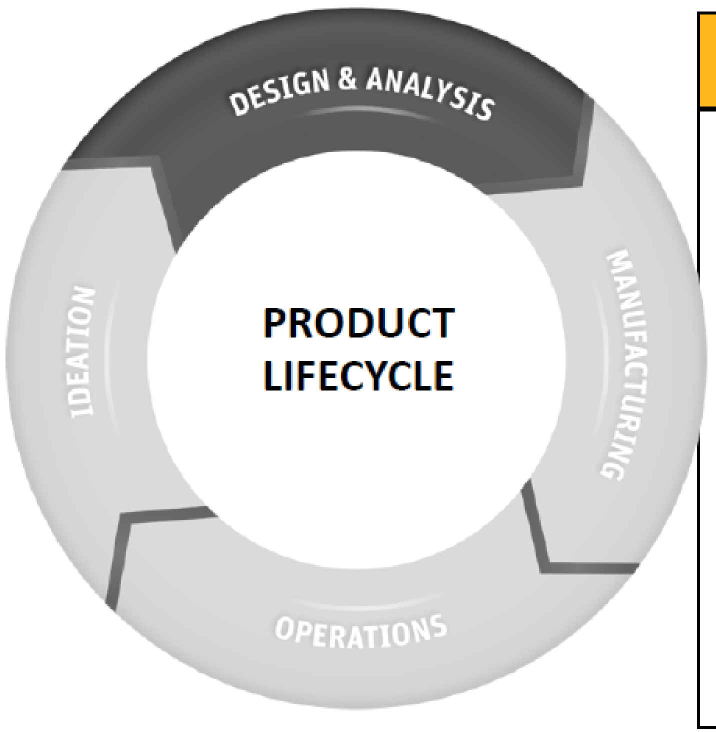
>150 CHANNEL PARTNERS GLOBALLY

Ansys

Ansys Offers the Only True Simulation Platform



Ansys' Simulation Provides Customers Top-Line Growth and Bottom-Line Savings



Simulation Impact

- Rapid innovation
- Lower cycle time
- Reduced risks
- Increased quality
- Manage complexity

Revenue Growth

- Offer more products
- Launch right products
- Faster time to market

Cost Savings

- Improved R&D efficiency
- Fewer physical prototypes
- Lower warranty costs

Outline

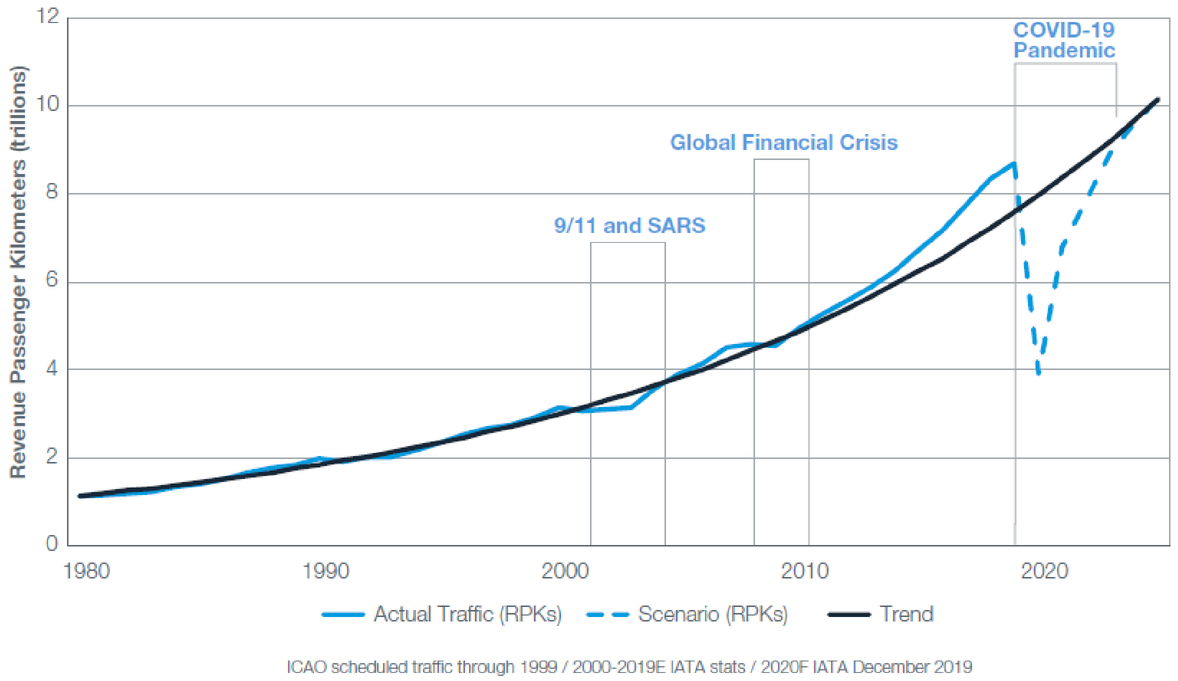
- COVID-19: Effect and Response from Airline Industry
- How Simulation can support disinfecting and cleaning solutions
  - Cabin HVAC & Air Quality
  - PPE Effectiveness
  - Disinfecting air and surfaces – UV Light and Electrostatic Spray

Impact of COVID-19 on Commercial Air Travel

- The current global pandemic caused by COVID-19 has impacted people around the world and has caused many industries to come to a halt due to the risks of transmission.

- One key reason for the pandemic is the highly contagious nature of the virus particles. The three primary routes of coronavirus transmission are:
  - Airborne particles
  - Droplets from a cough or sneeze
  - Touching a surface with infected particles

- Air travel has been greatly affected by the pandemic because of:
  - Proximity of passengers in an enclosed environment and
  - Long duration of flights

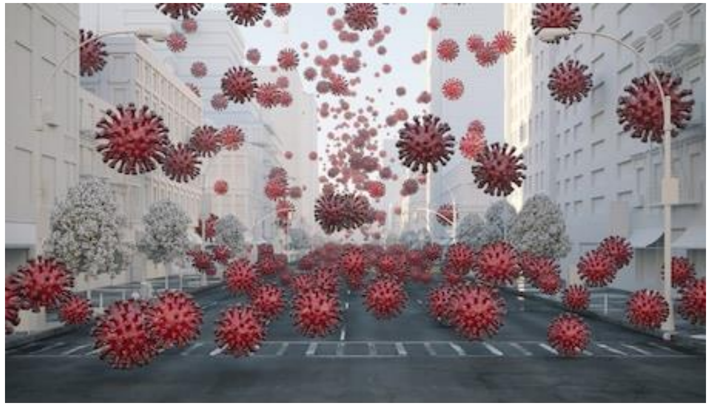


Source: Boeing 2020 CMO Report

Objective: Develop best-practices and solutions for the new-normal to restore people's confidence in air travel

Multiple Solutions Required to Ensure Our Safety

- All routes of transmission will have to be considered as there is no single solution to disinfect the air we breathe and the surfaces we touch



Heating Ventilation & Air Conditioning (HVAC) in the vehicles will need to be studied and optimized

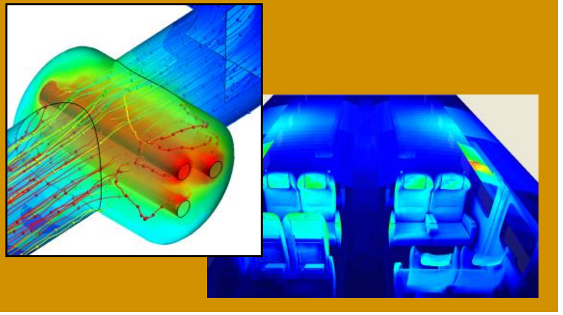
Surface disinfection via mobile or installed UV systems or sprays

Computer simulation can provide guidance

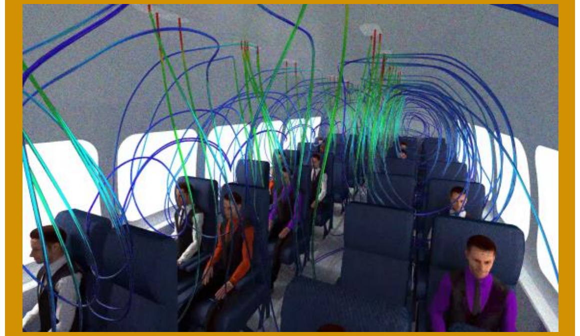
High-fidelity, physics-based engineering analysis can help optimize the design and operation of existing ventilation systems as well as UV disinfection system of air and surfaces.

Ansys Solutions for Pathogens Neutralization Inside a Cabin

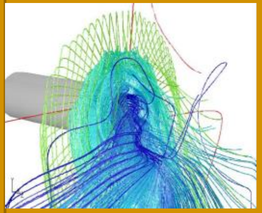
UV Sterilization
- Use UV light to sterilize recirculating air in HVAC
- Design system for efficient surface disinfection
- Ensure proper dosage to neutralize virus load



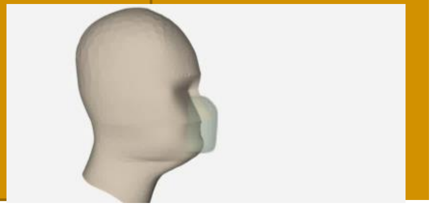
Cabin HVAC System
- Analyze flow patters
- Minimize recirculation
- Optimize vent operation
- Minimize spread of pathogens through air via scrubbing



Spray Disinfection
- Spray formation
- Evaluate spray dispersion and coverage
- Optimize transfer efficiency via electrostatics

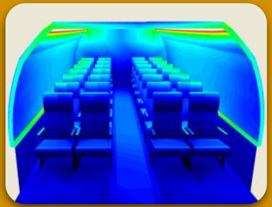


PPE (e.g. Mask) Effect
- Cough/sneeze droplets suppression
- Detail deposition pattern
- Dispersion

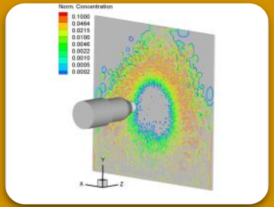


Case studies

Cabin HVAC system studies



Disinfection of cabin surfaces and HVAC air via UV light



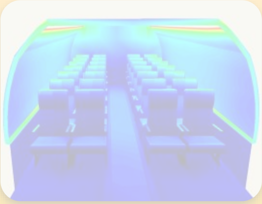
Disinfection of cabin via electrostatic sprays

Case studies

Cabin HVAC system studies

HVAC Airflow and Control System Modeling

Effect of wearing mask in the cabin



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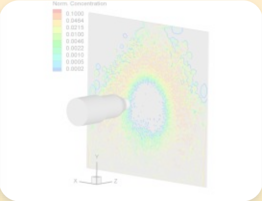
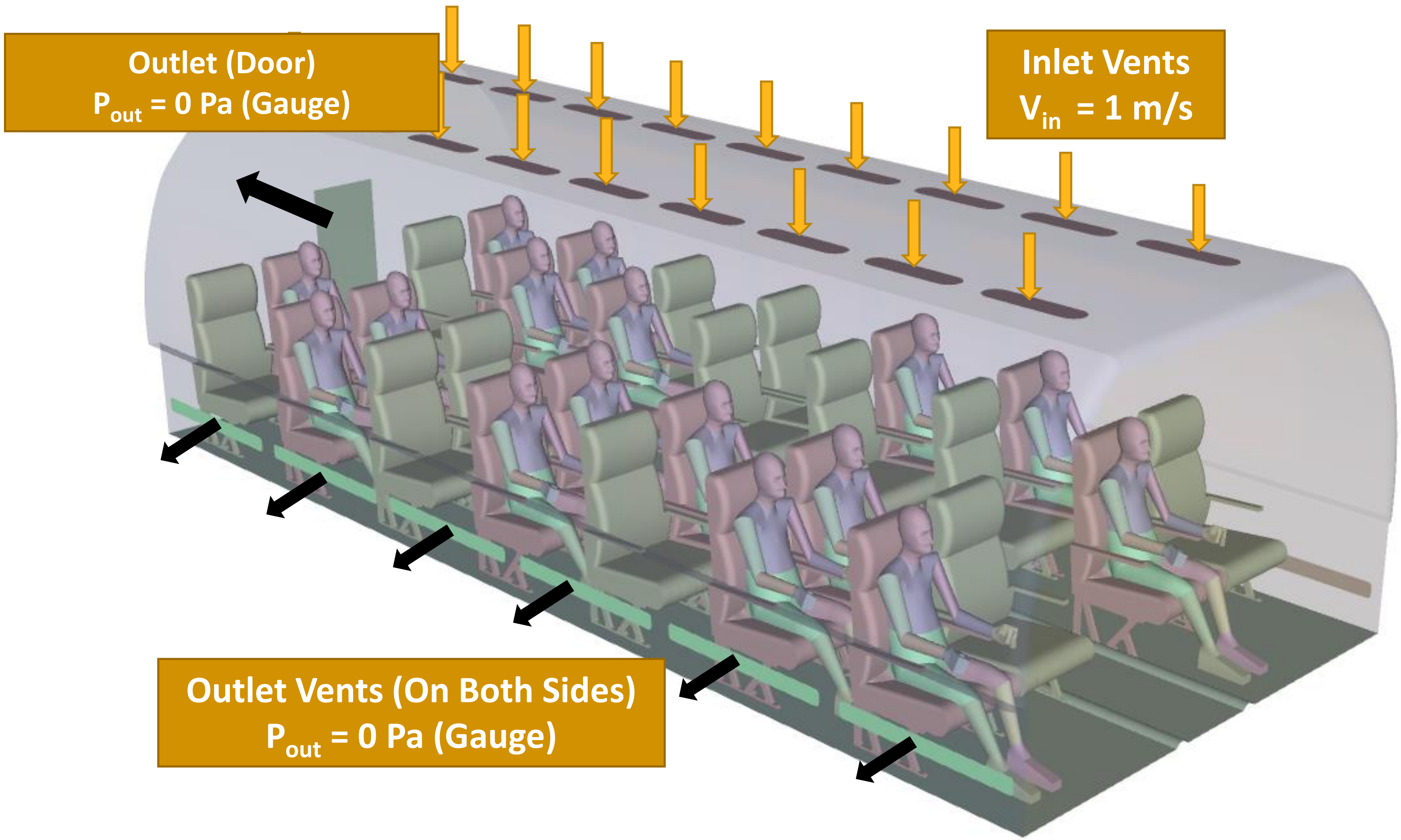
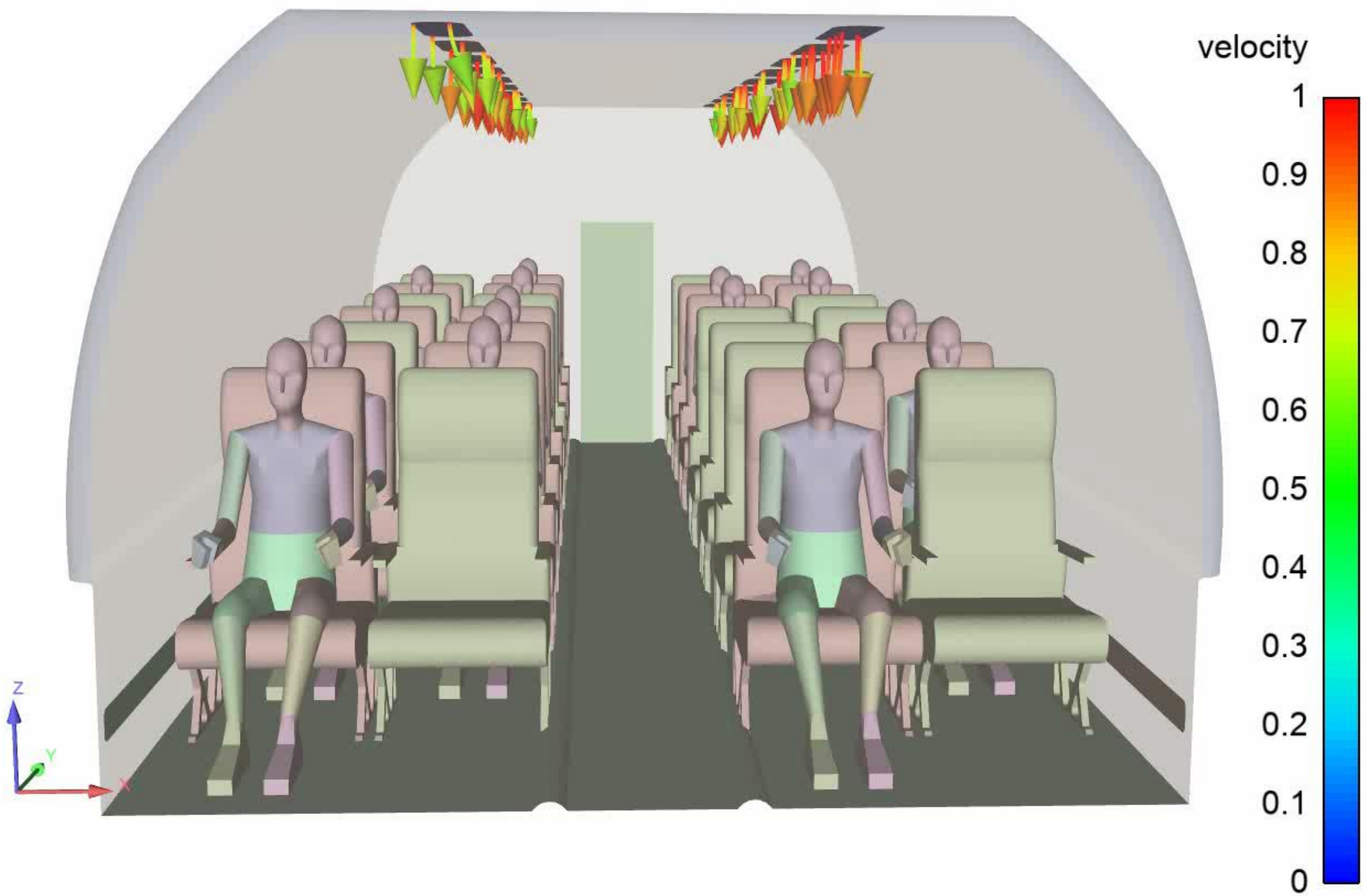


Disinfection of cabin via electrostatic sprays

Problem setup for Flow Analysis inside Cabin



Airflow Within Cabin



Ansys

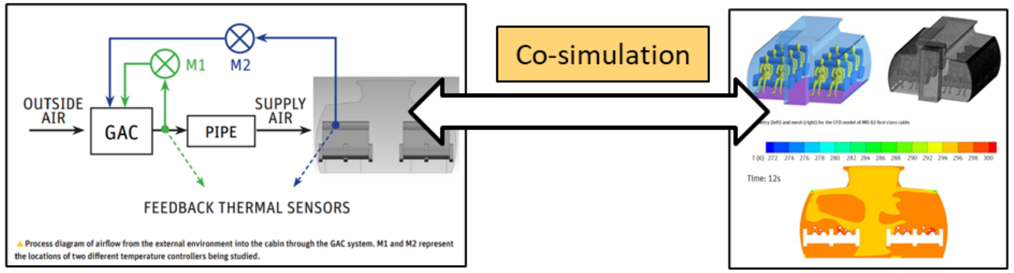
Optimal Control Design of an Aircraft Cabin HVAC

Appropriate control system for air conditioner

Accurate predictions in HVAC

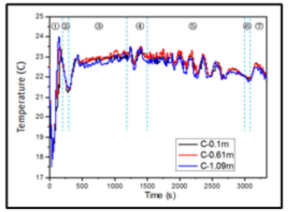
Speed, scalability, traceability

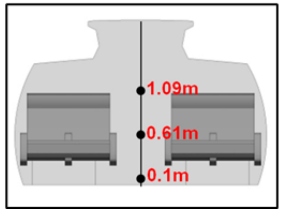
System Simulation



1D simulation by Ansys TwinBuilder

3D unsteady CFD by Ansys Fluent



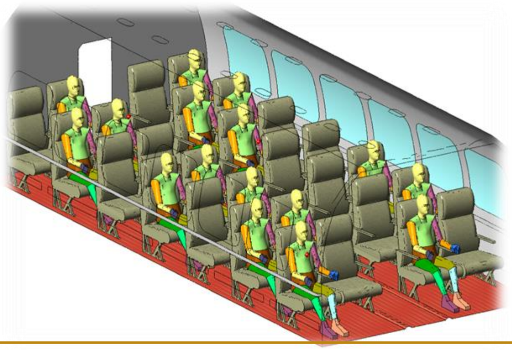


Complex geometry

Heat generation from human body

Radiation

Humidity



Natural convection

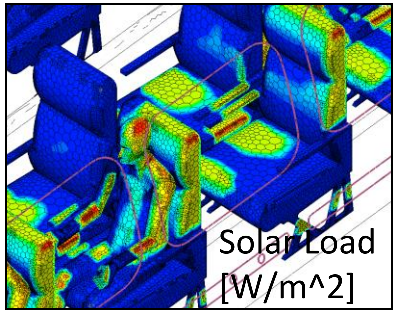
Temperature

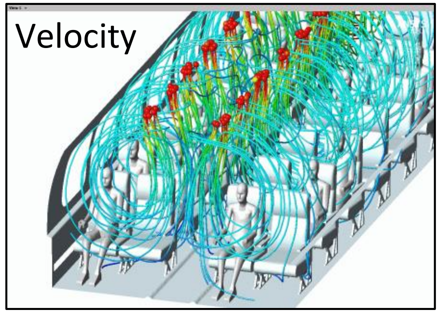
Solar Load

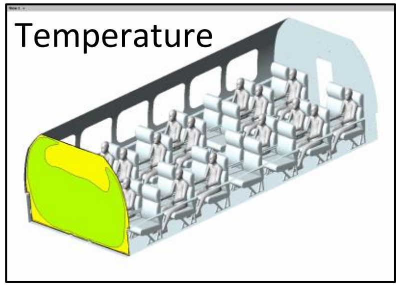
Unsteady velocity

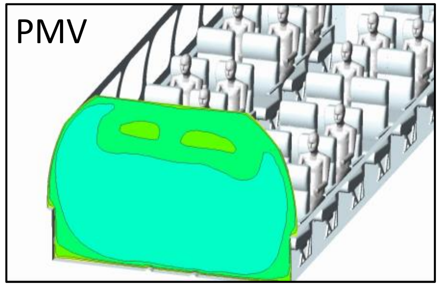
Non-linear physics

Unsteady simulation





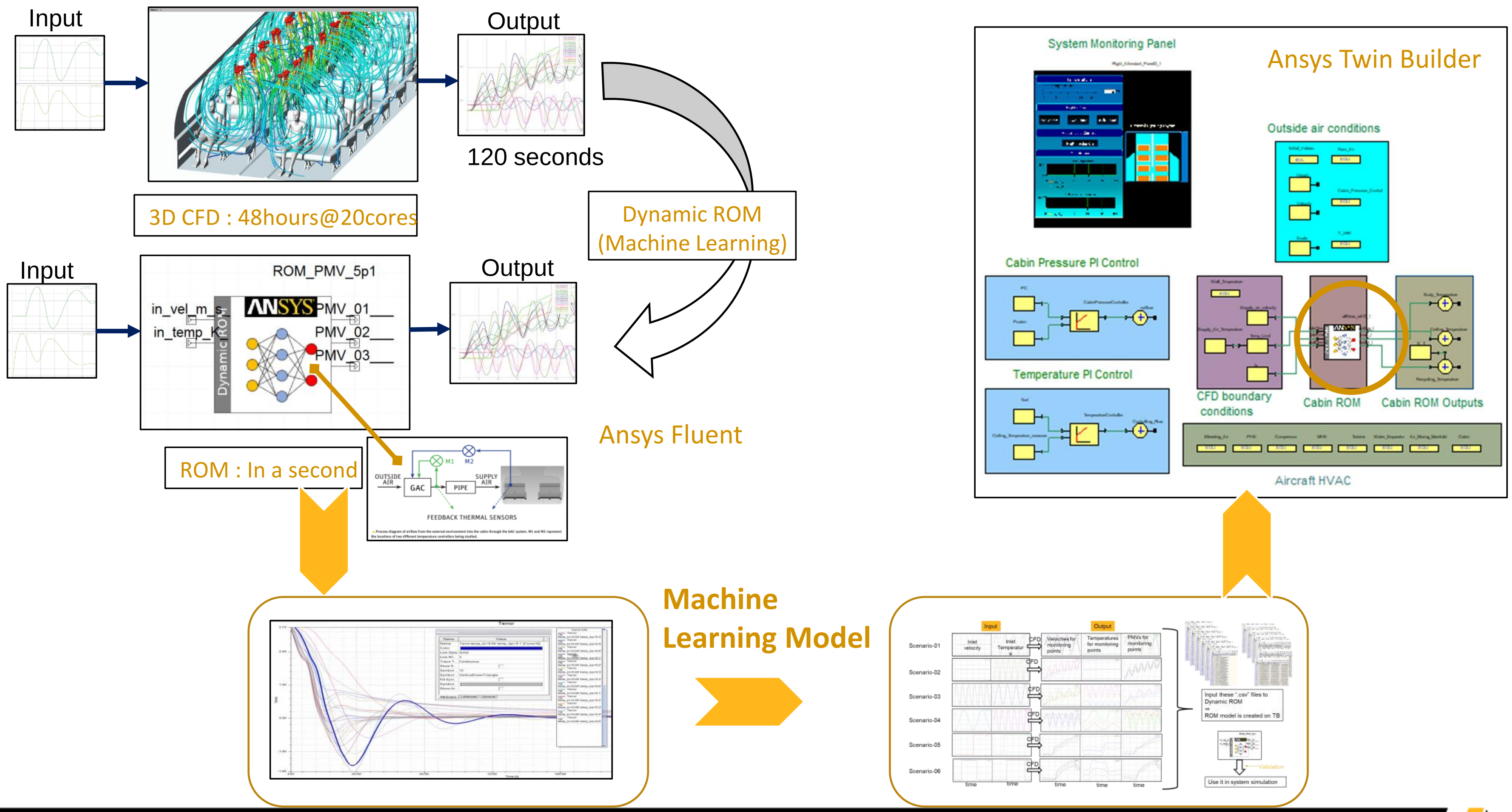




HVAC Digital Twin

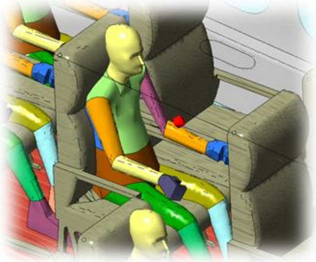
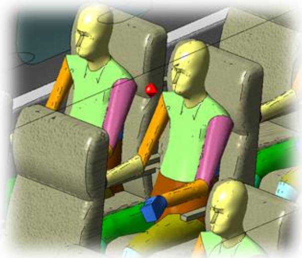
Generate Prediction Model based on 3D CFD

Embedded into System Model

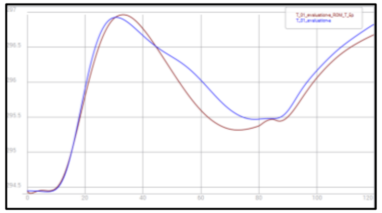
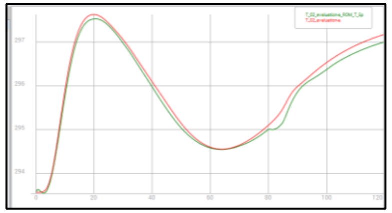
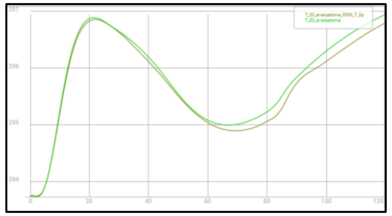


Model Validation: ROM vs. High-Fidelity Data

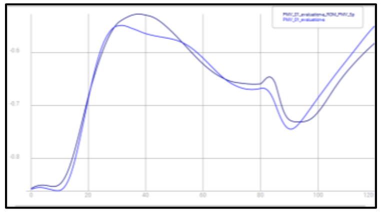
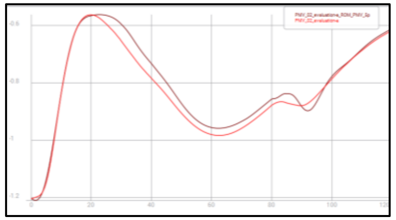
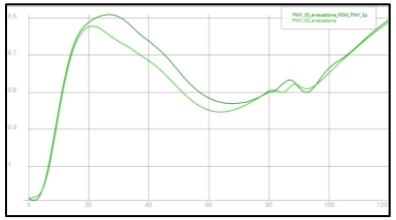
Prediction Confidence

Location-1	Location-2	Location-3
		

Temperature

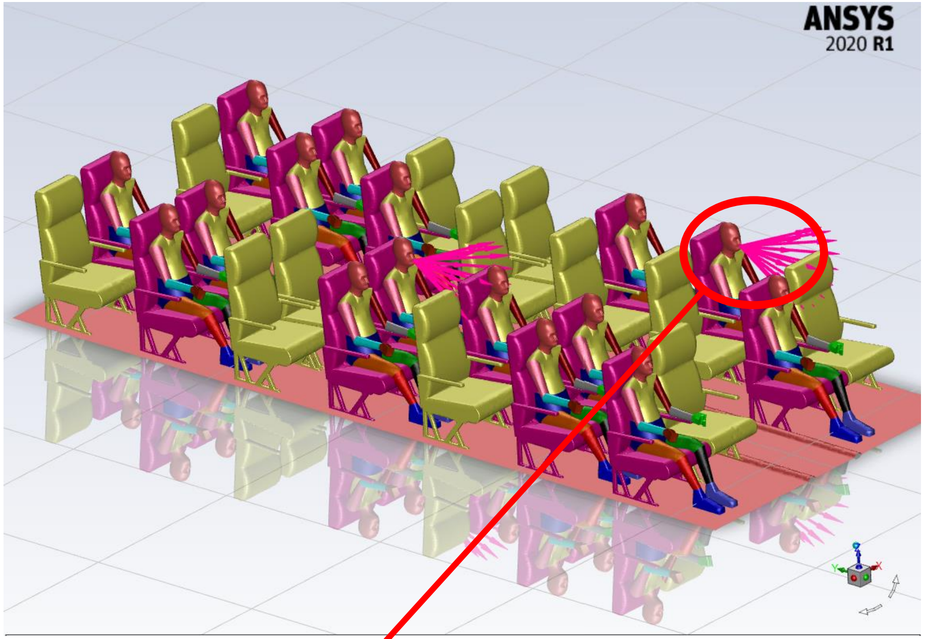
Thermal Comfort Index

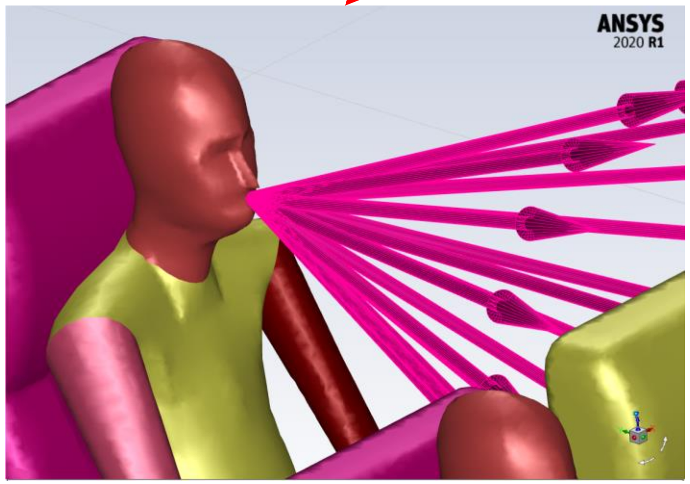




- **Predictive Analytics:** Heterogenous and Open Architecture
- **MBE Approach:** Physics Based Component Models for System-of-System Analysis
- **Configuration Management:** Rapid evaluation of different configurations
- **Digital Twin Integration:** Connectivity with PLM/ERP system

Case 1: Cough Simulation Without Mask

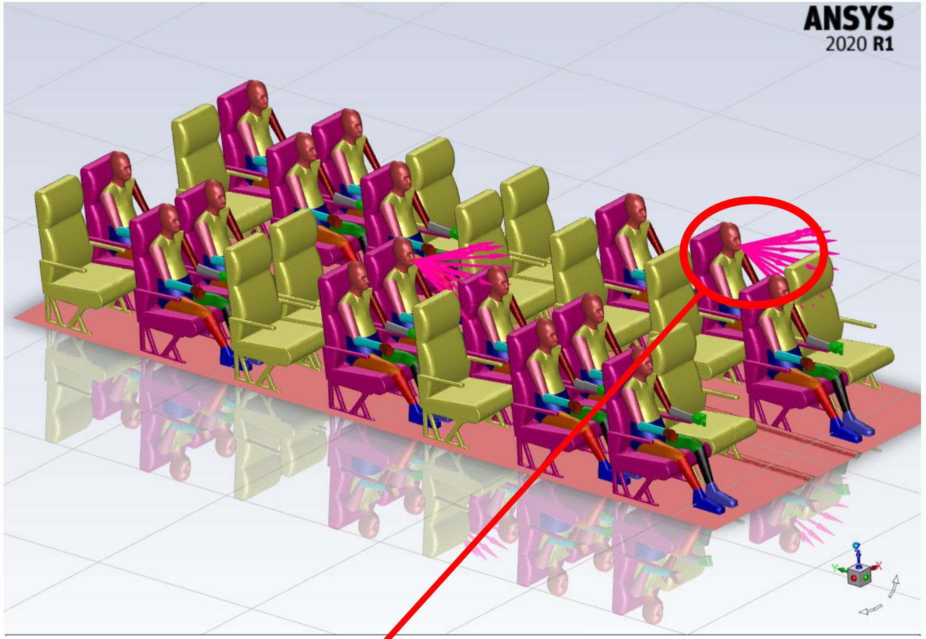
- Simulation set up with two people coughing in the cabin
- Cough times are staggered
- Coughing parameters are same for both the coughs
  - Rosin-Rammler droplet size distribution: min size: 2 μm, max size: 75 μm, mean size: 20 μm
  - Cough velocity: 11m/s directed straight outward from mouth
  - Cough spray modeled as water, using a cone injection with a cone angle of 24^o
  - Mass flow rate of cough: 1.95e-3 kg/s
  - DPM simulation solved in a frozen air flow field



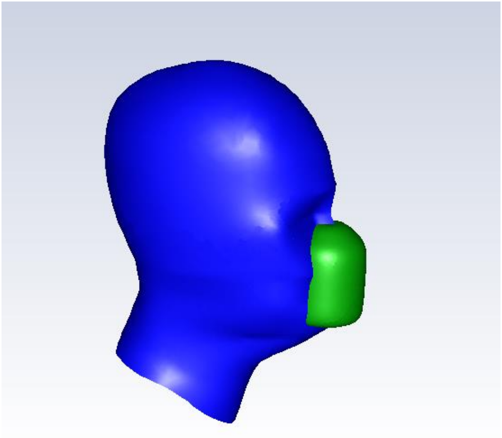


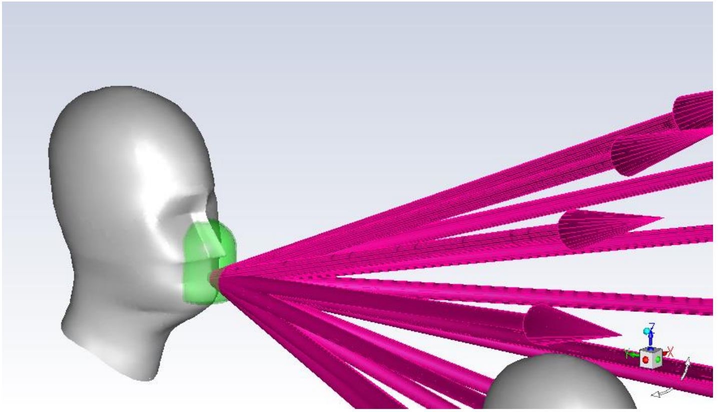
Ref: Bourouiba, L., Dehandschoewercker, E., & Bush, J. (2014). Violent expiratory events: On coughing and sneezing. *Journal of Fluid Mechanics, 745*, 537-563. doi:10.1017/jfm.2014.88

Case 2: Cough Simulation with Mask



- Add effect of mask on Row 2 (front) passenger
- A generic mask is used
  - Mask modeled using porous media and UDF for filtering cough droplets
- All coughing parameters same as before





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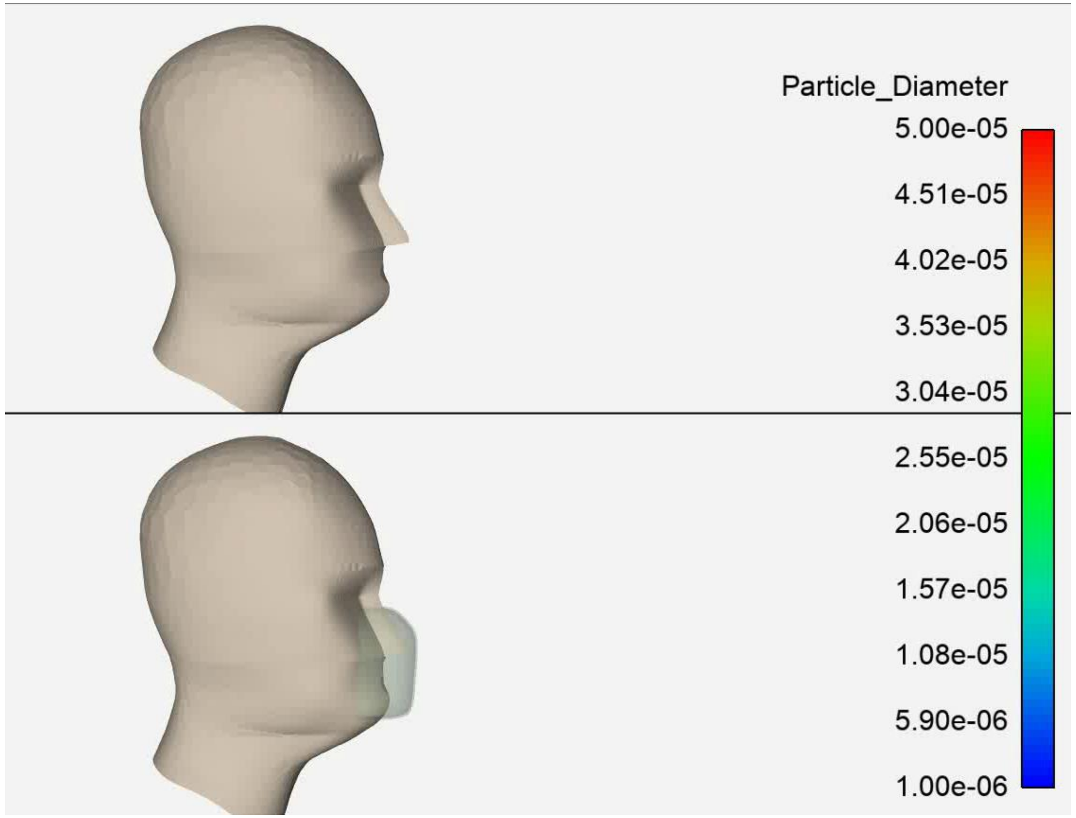
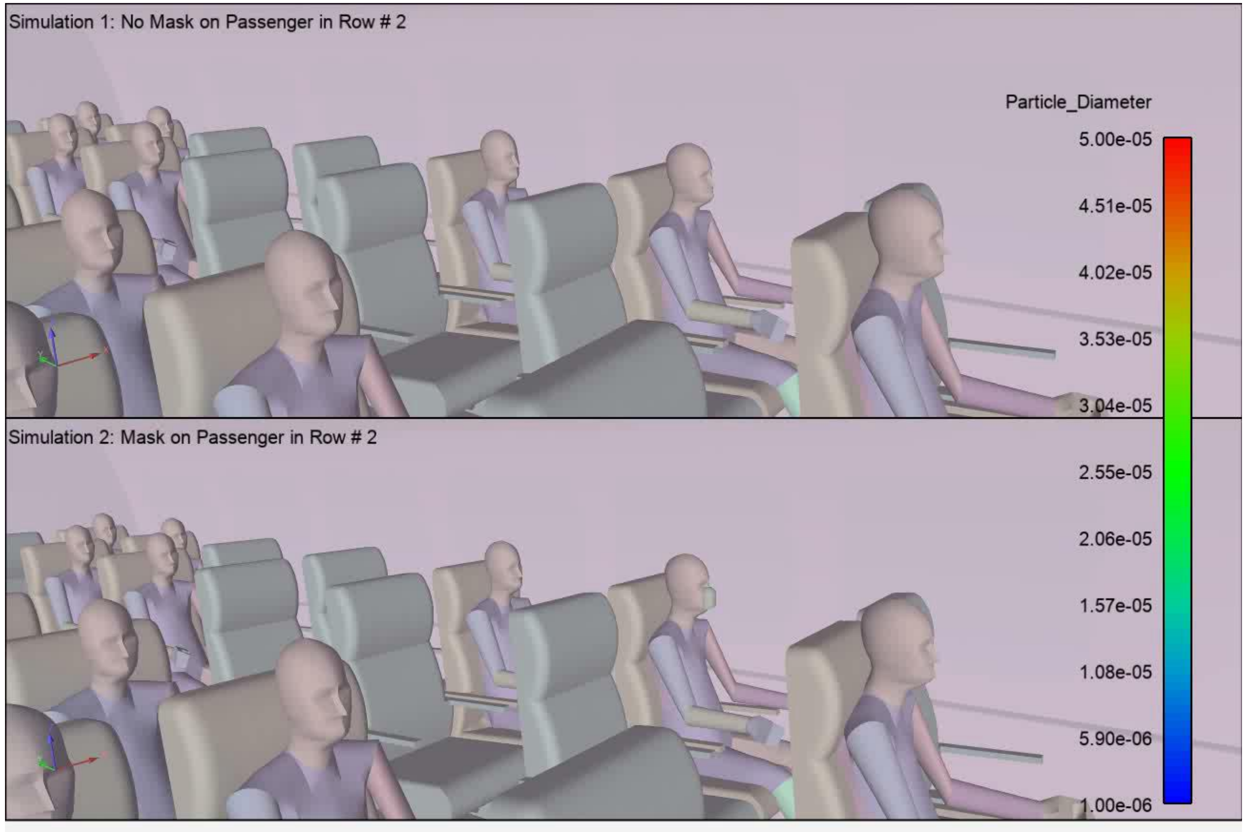
Vivek Kumar,et al., On the utility of cloth facemasks for controlling ejecta during respiratory events., arXiv: Medical Physics, 2020.

Analysis of Cabin HVAC system: Coughing With and Without Mask

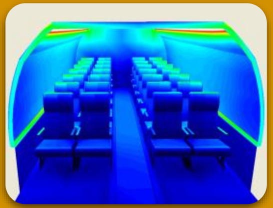




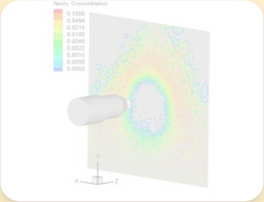
Ref: Vivek Kumar et al., On the utility of cloth facemasks for controlling ejecta during respiratory events., arXiv: Medical Physics, 2020.

Case Studies

Cabin HVAC system studies



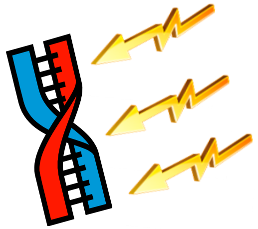
Disinfection of cabin surfaces and HVAC air via UV light

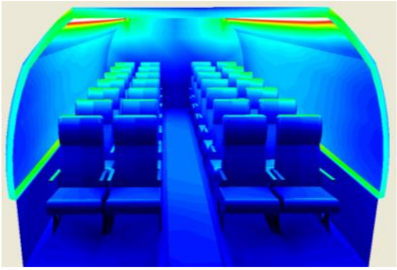


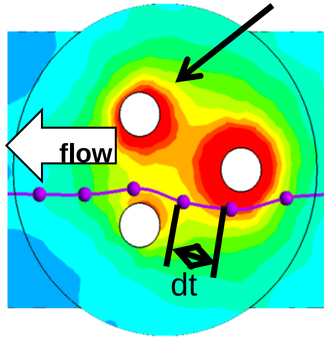
Disinfection of cabin via electrostatic sprays

UV Light for Disinfecting Surfaces

- Disinfection efficiency depends on:
  - Wavelength & Intensity: Lamp output
  - Exposure time: **design of disinfection system**
- Disinfection efficiency is defined as **"UV Dosage"**
  - **UV Dosage:** Amount of received radiation in micro-organisms, either from continuous exposure or during the flow path in reactor





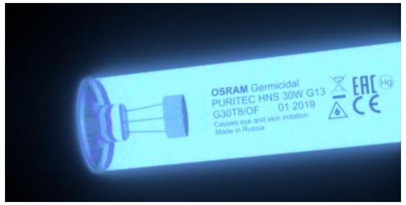


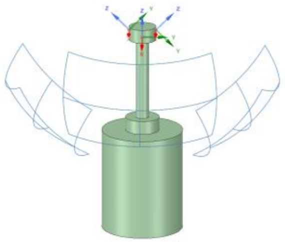
$$UV\ Dose: \int_t (UV\ Intensity) * dt$$

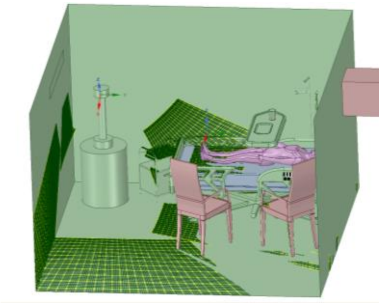
Challenges

- Choosing the **optimal lighting system**
- Ensuring **complete exposure** and **irradiation** of all relevant surfaces including line of sight challenges
- **Method of delivery:** Installed vs. mobile
- **Optimizing the design, path and speed** of a mobile system (if mobile)
- Understanding the **dosage requirements**

Ansys / SPEOS







Simulation Workflow

Model Setup

- Create 3D model of area under test (e.g. hospital, airport, factory, aero cabin)
- Define optical properties
- Define light delivery system & motion path (if applicable)

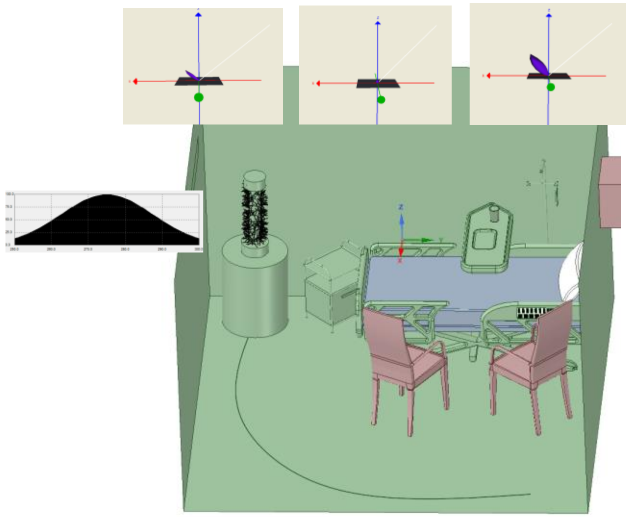
Solve

- Run Simulations (scalable – HPC enabled)

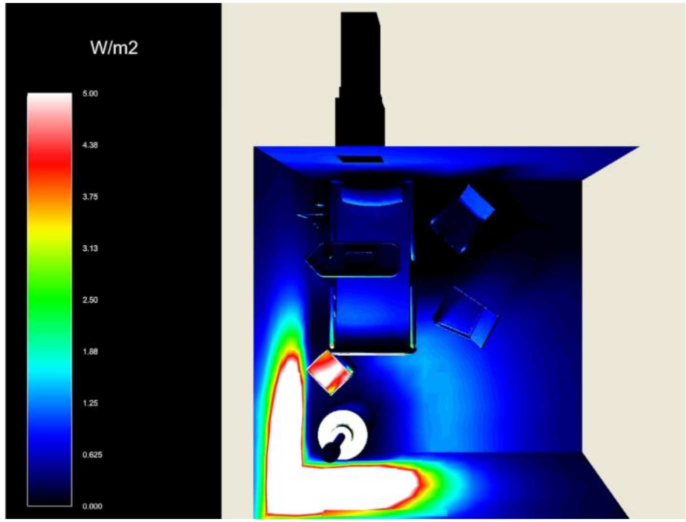
Analyze Results

- Calculate cumulative irradiation on all surfaces
- Determine necessary exposure requirements (or speed requirements for mobile solution)
- Verify that there are no missed surfaces

Ansys / SPEOS

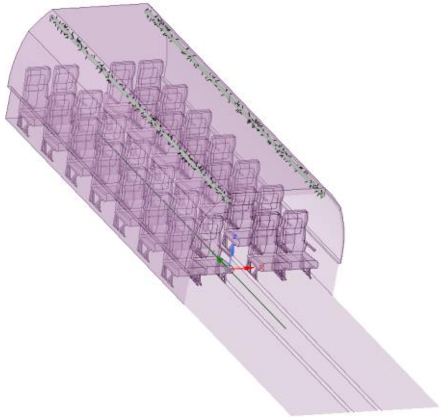


Irradiation of room

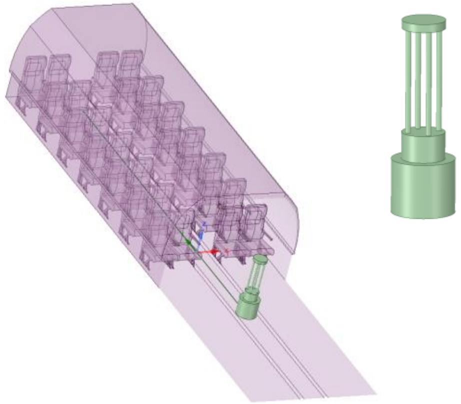


Aircraft Cabin Case Study

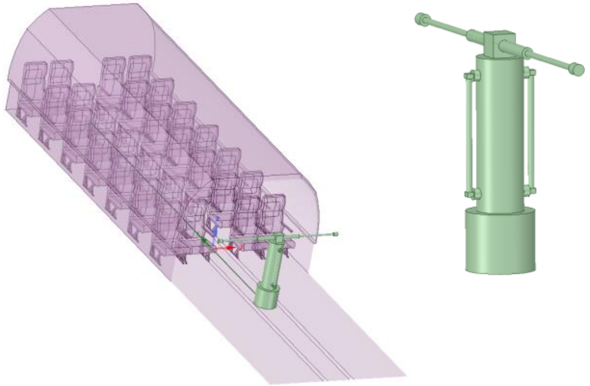
Installed lights

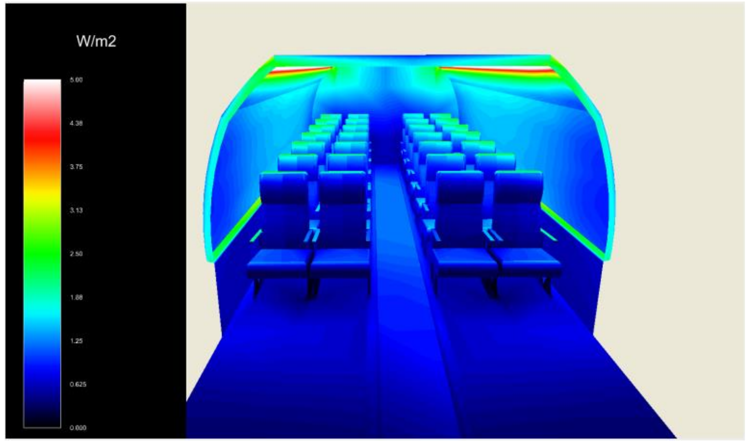


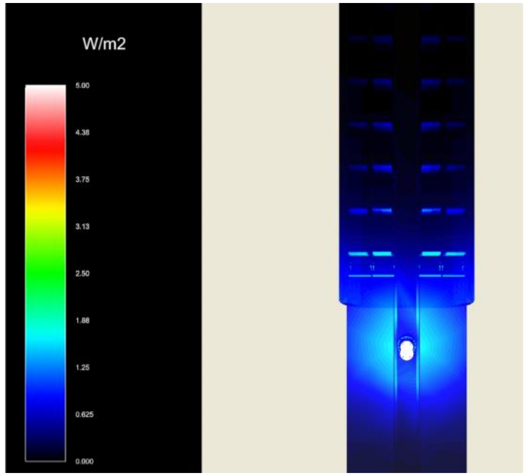
Mobile design 1

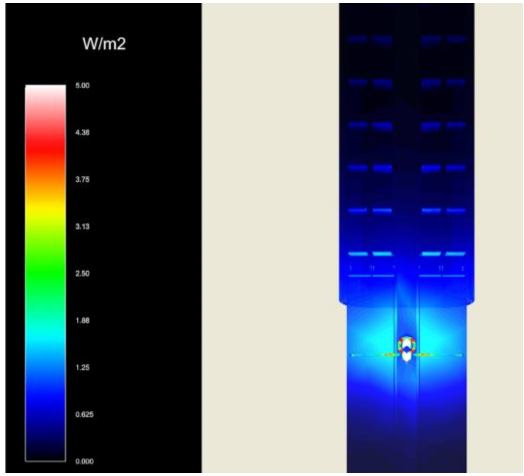


Mobile design 2







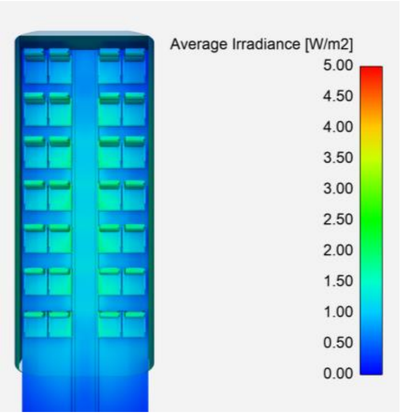


Outcomes: optimal lighting configuration, design of the system, dosage requirements etc.

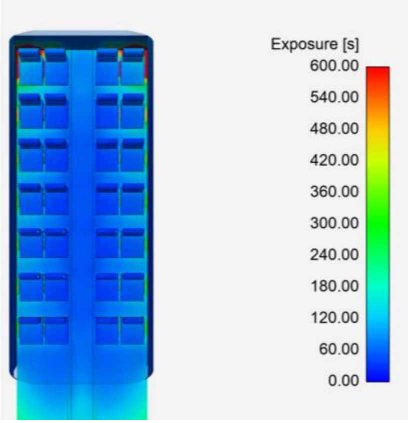
Aircraft Cabin Case Study - Results

Cumulative irradiation & dosage requirements

Installed lights

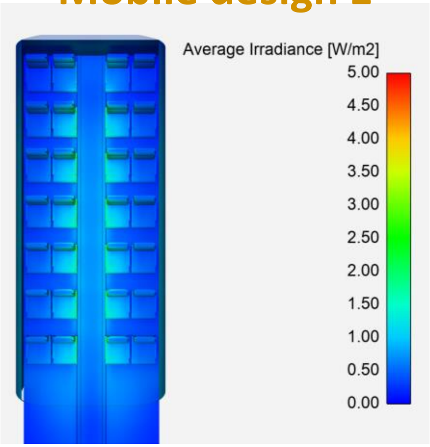


Lowest irradiance surface: ~4 uW/cm2

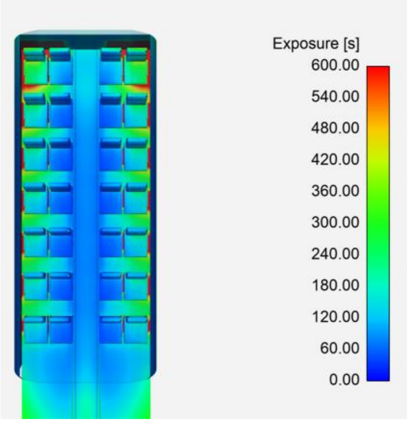


Exposure time required: 150s
Speed required: N/A

Mobile design 1

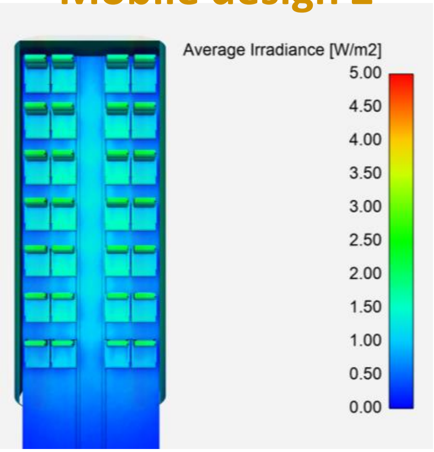


~1 uW/cm2

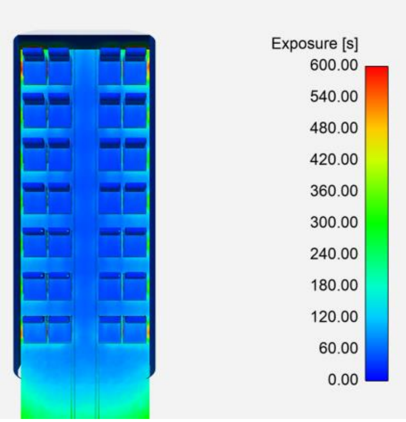


Exposure time required: 600s
Speed required: 0.034 m/s

Mobile design 2



~6 uW/cm2



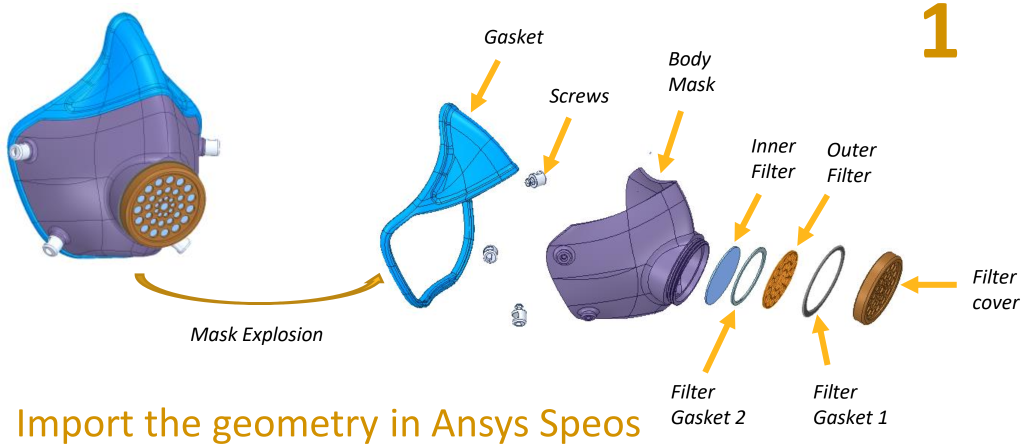
Exposure time required: 100s
Speed required: 0.204 m/s

Aircraft Cabin Case Study

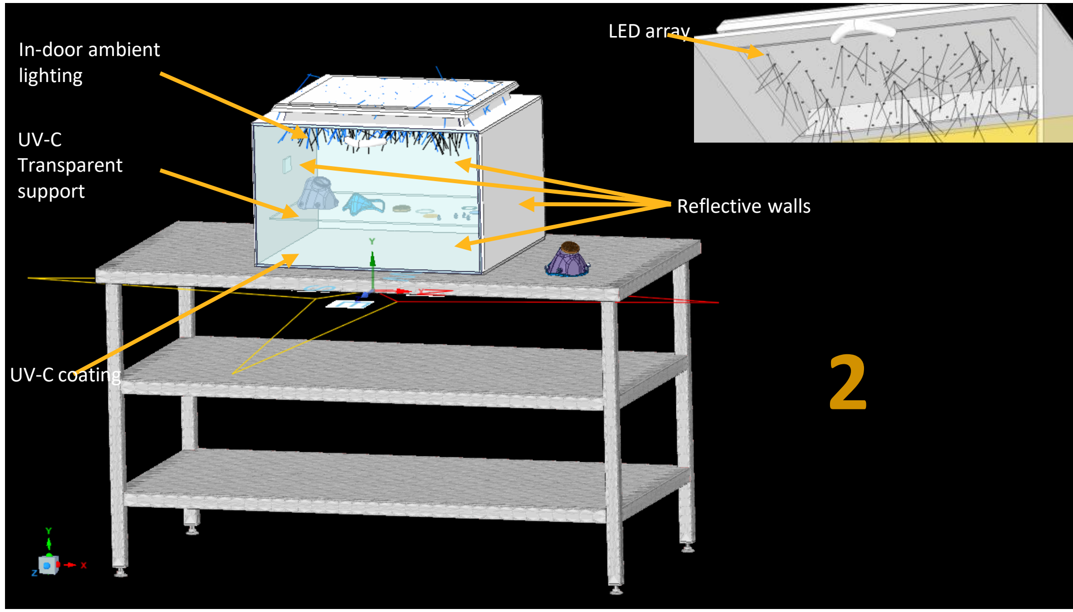
Mobile UV Ray Disinfection System

Mask Disinfection with UV Light

1



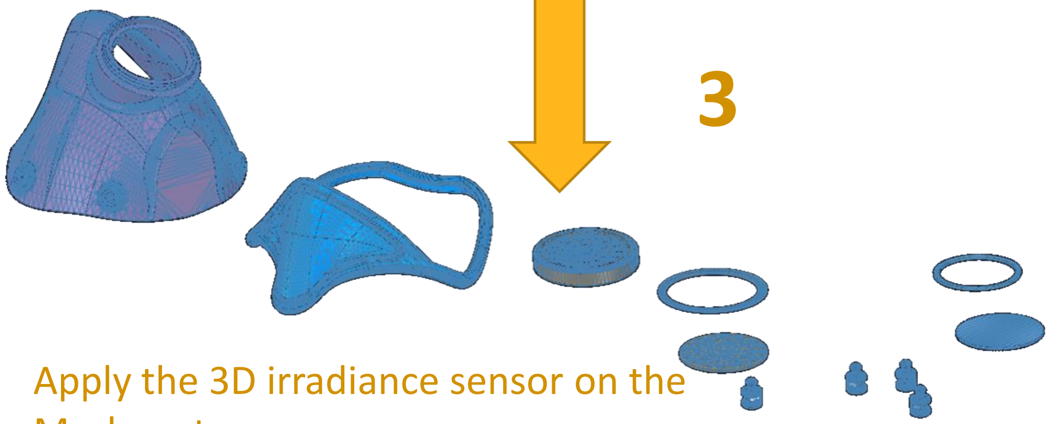
Import the geometry in Ansys Speos



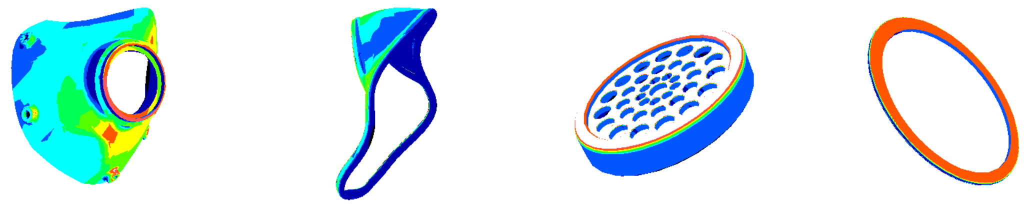
2

Define the materials propreties and sources

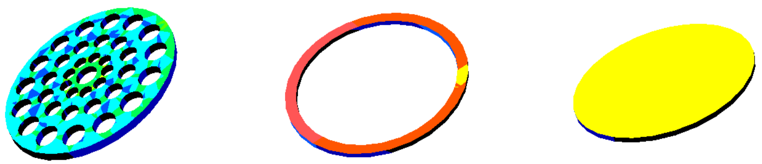
3



Apply the 3D irradiance sensor on the Mask parts

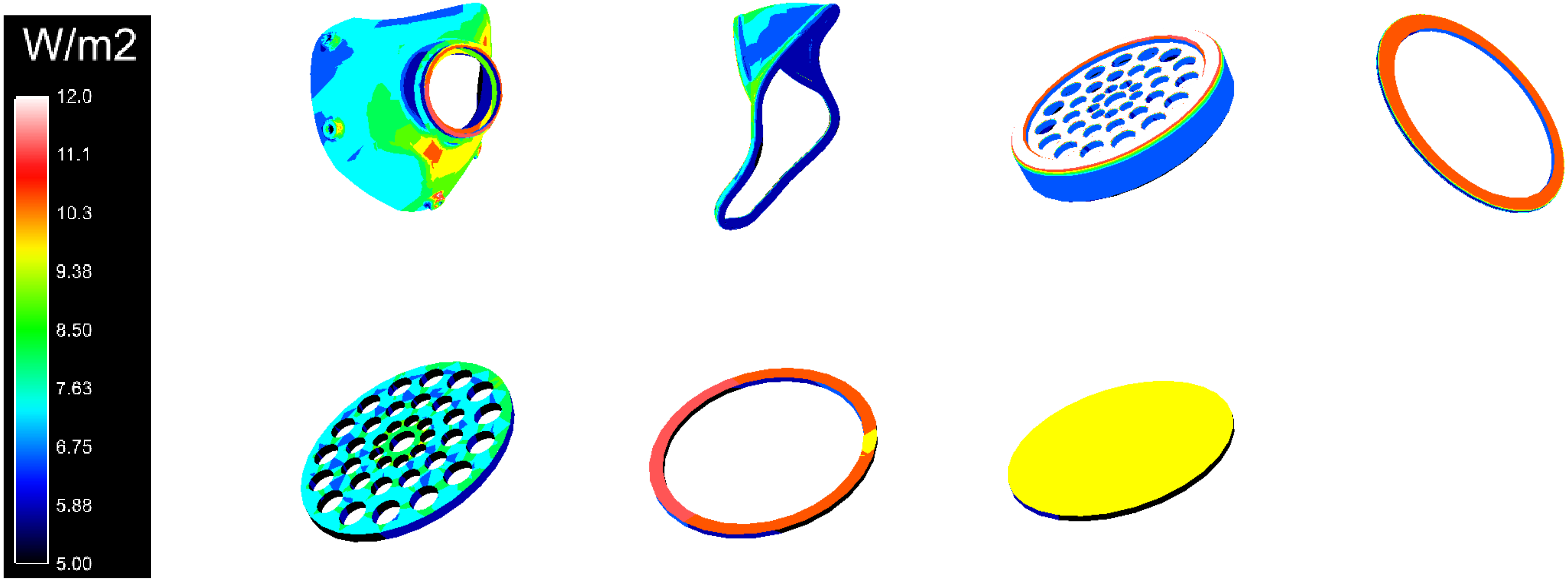


Analyse the radiometric resuts



4

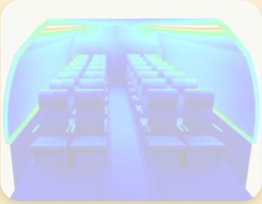
Mask Disinfection with UV Light



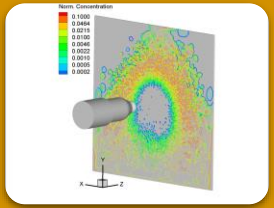
The radiometric analysis shows **minimum irradiance of 0.74 W.m^{-2}** to achieve **minimum criteria of 20 W.s.m^{-2}**. Desinfection process takes **27 seconds**.

Case studies

Cabin HVAC system studies

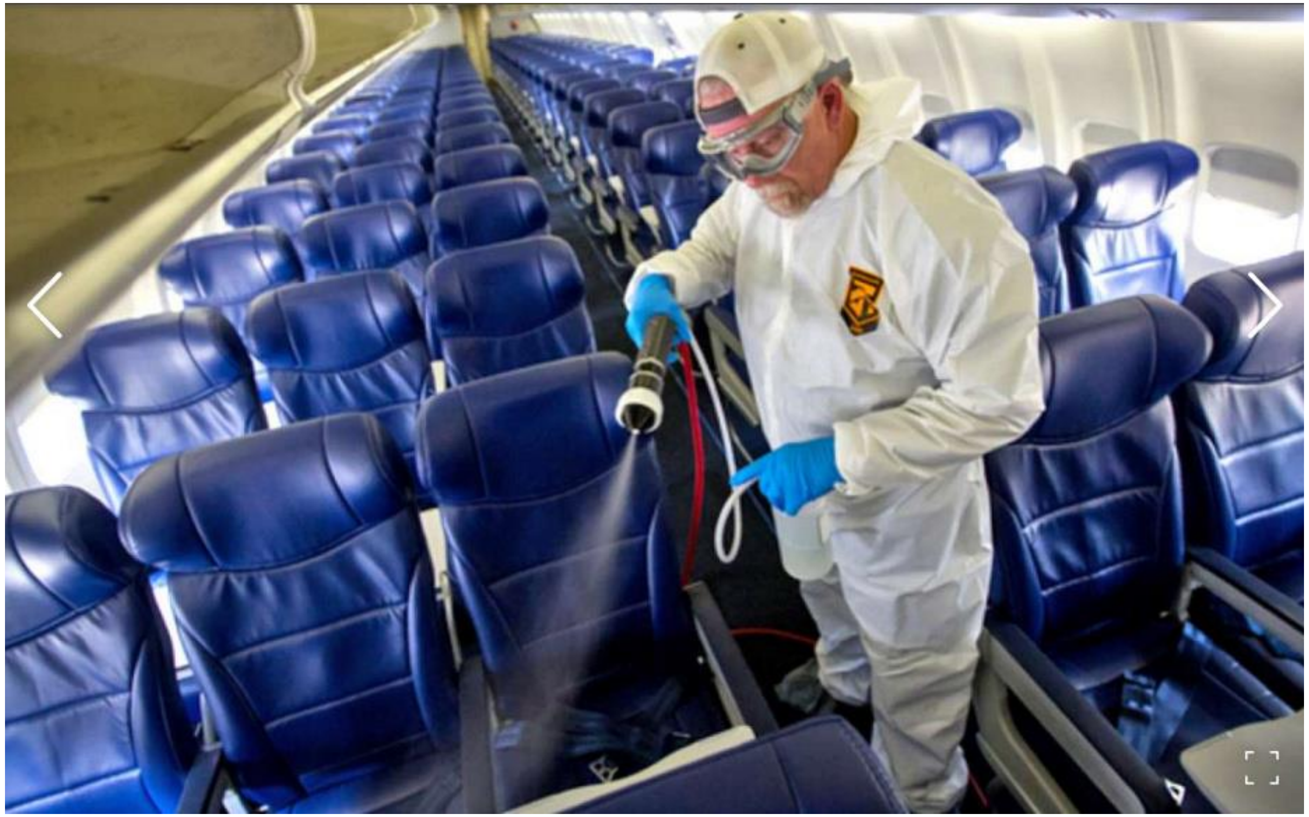


Disinfection of cabin surfaces and HVAC air via UV light



Disinfection of cabin via electrostatic sprays

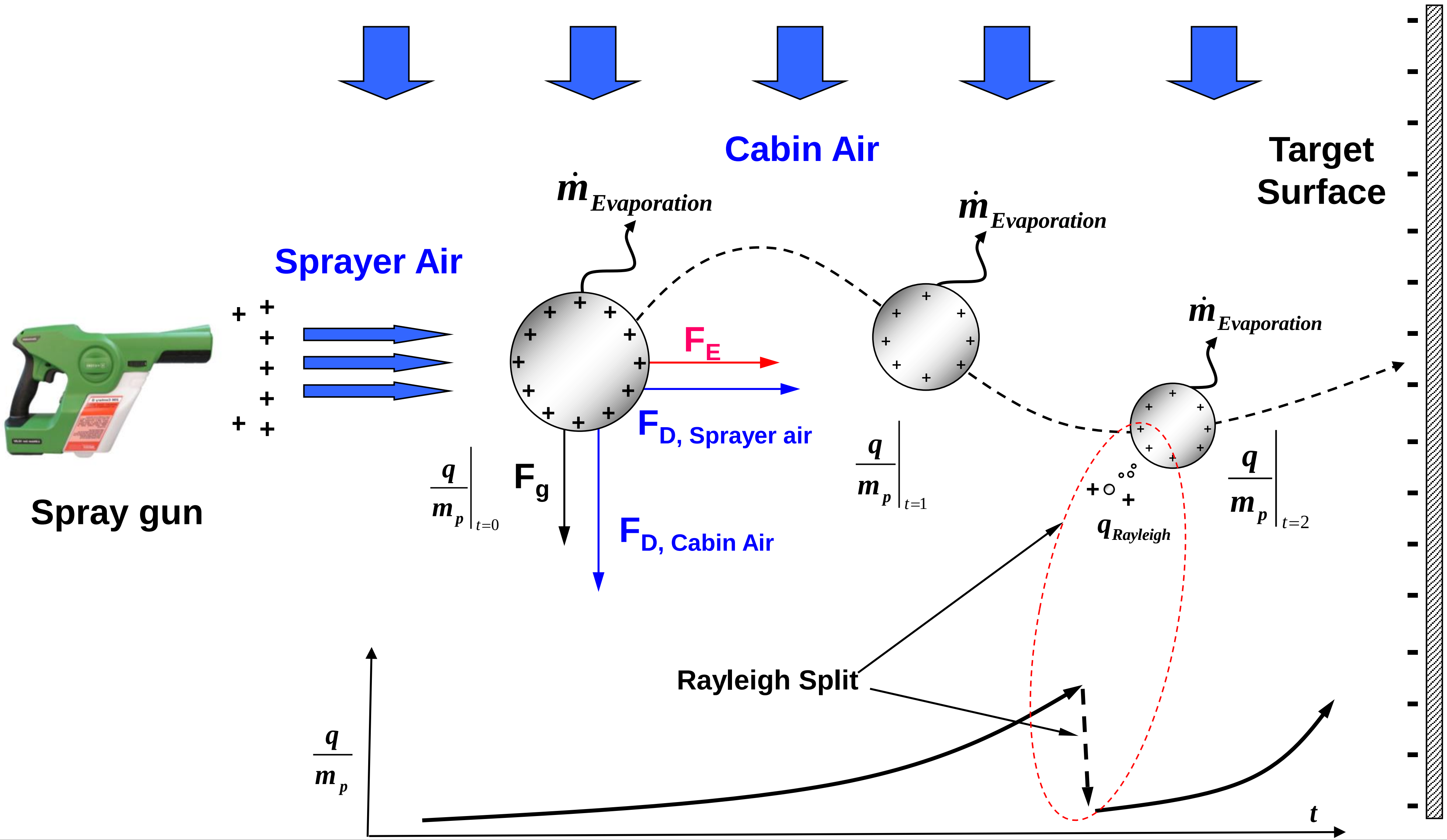
Electrostatic Sprays to Disinfect Aircraft Cabins in Between Flights



Courtesy: The Houston chronicle

- Optimize flight turn-around time
- Ensure that frequently touched surfaces are clean

Basic spray droplet physical model: forces acting on spray droplets

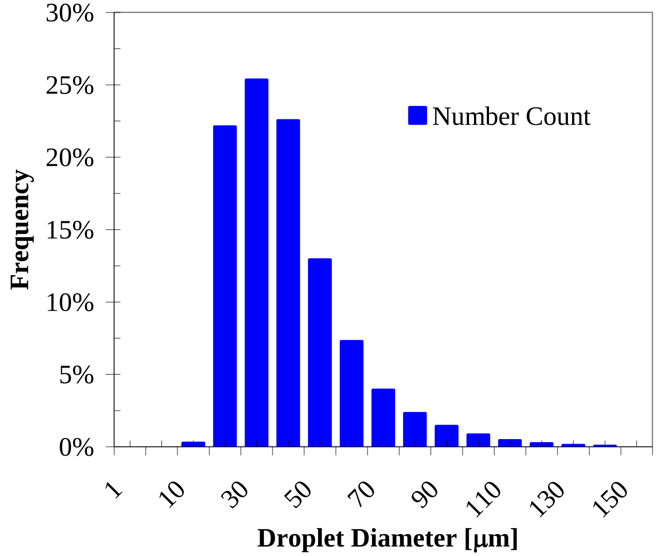


Particle Size Distribution: Experimental or Computed

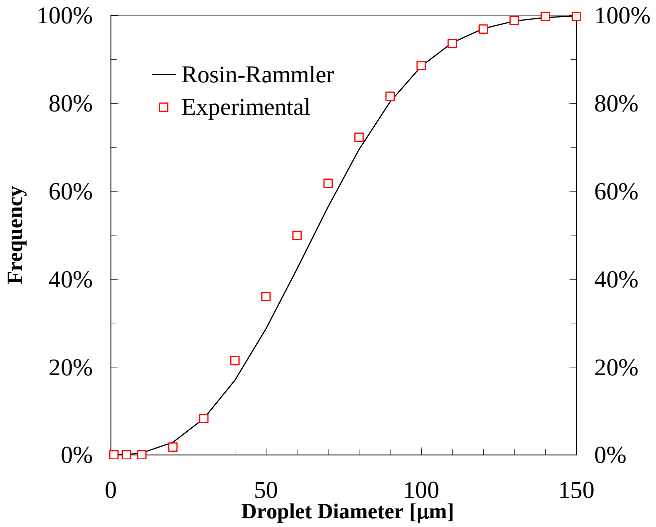
Experimentally measured

Computed using VOF/DPM

Size distribution



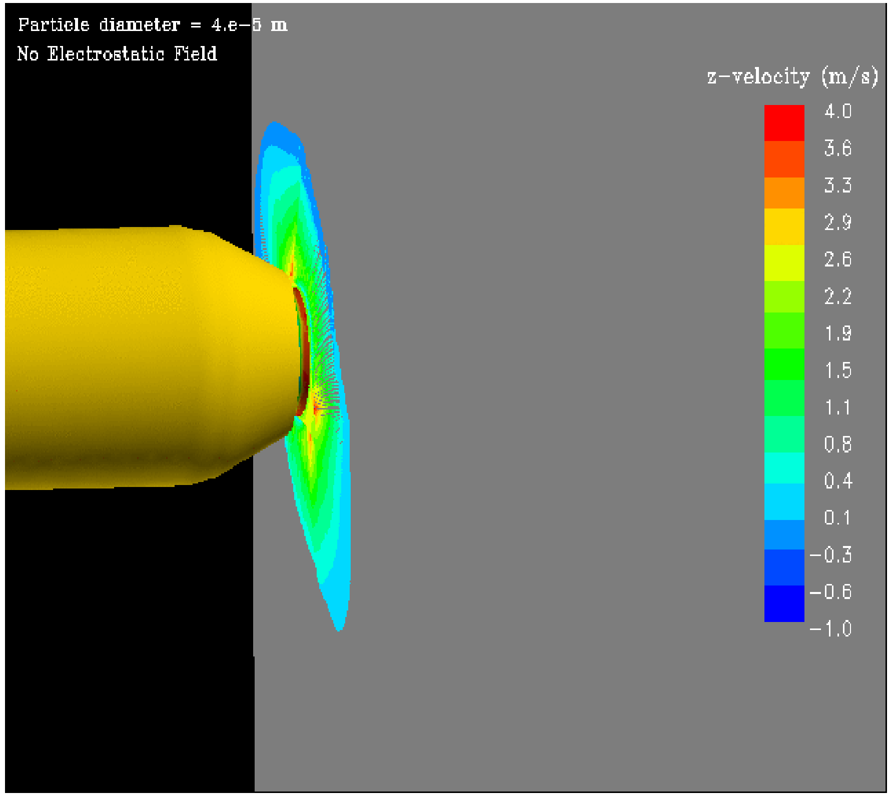
Cumulative mass distribution



Effect of the Electrostatic Field on Spray Droplet Trajectories

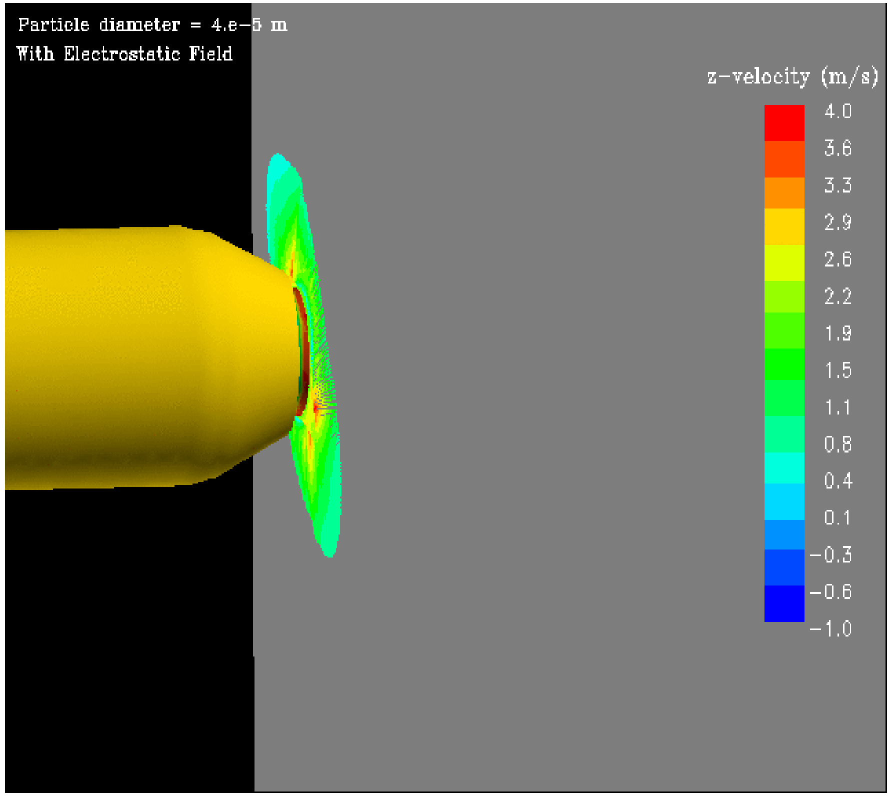
No Electrostatic Field

$\eta_{Transfer}$ **~ 20%**



With Electrostatic Field

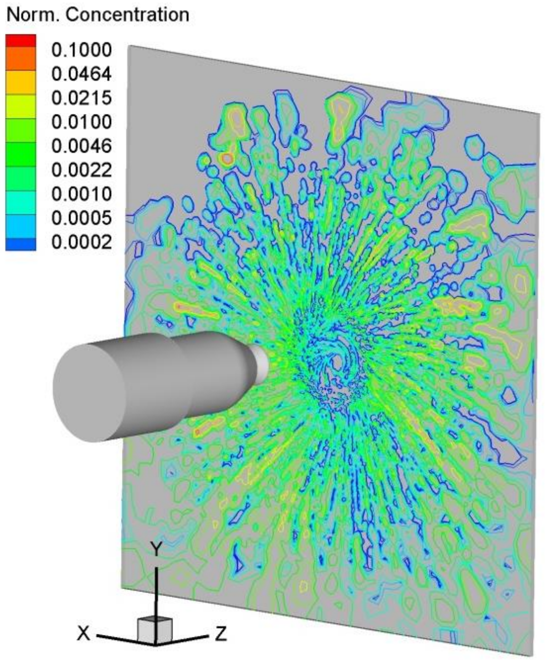
$\eta_{Transfer}$ **~ 78%**



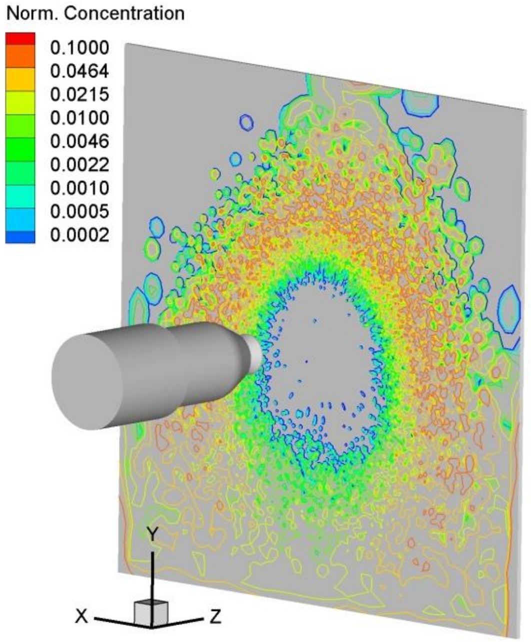
Droplet diameter = 40μm
Particle charge density = 0.874×10^{-3} C/kg

Disinfectant Film Thickness on Target Surface

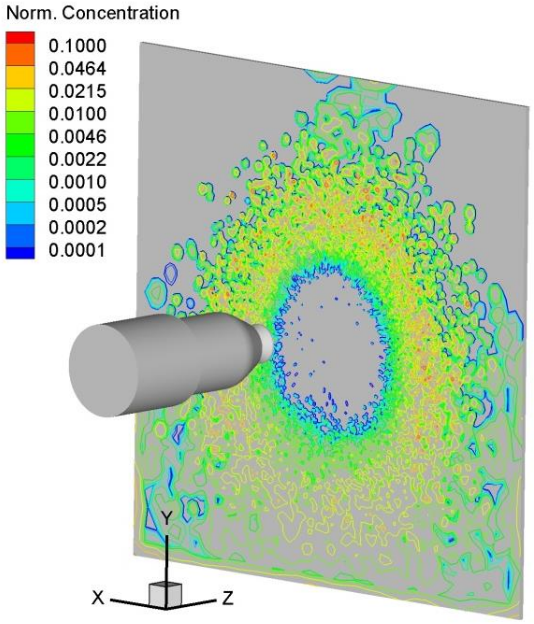
No e-field



90 kV, no space charge

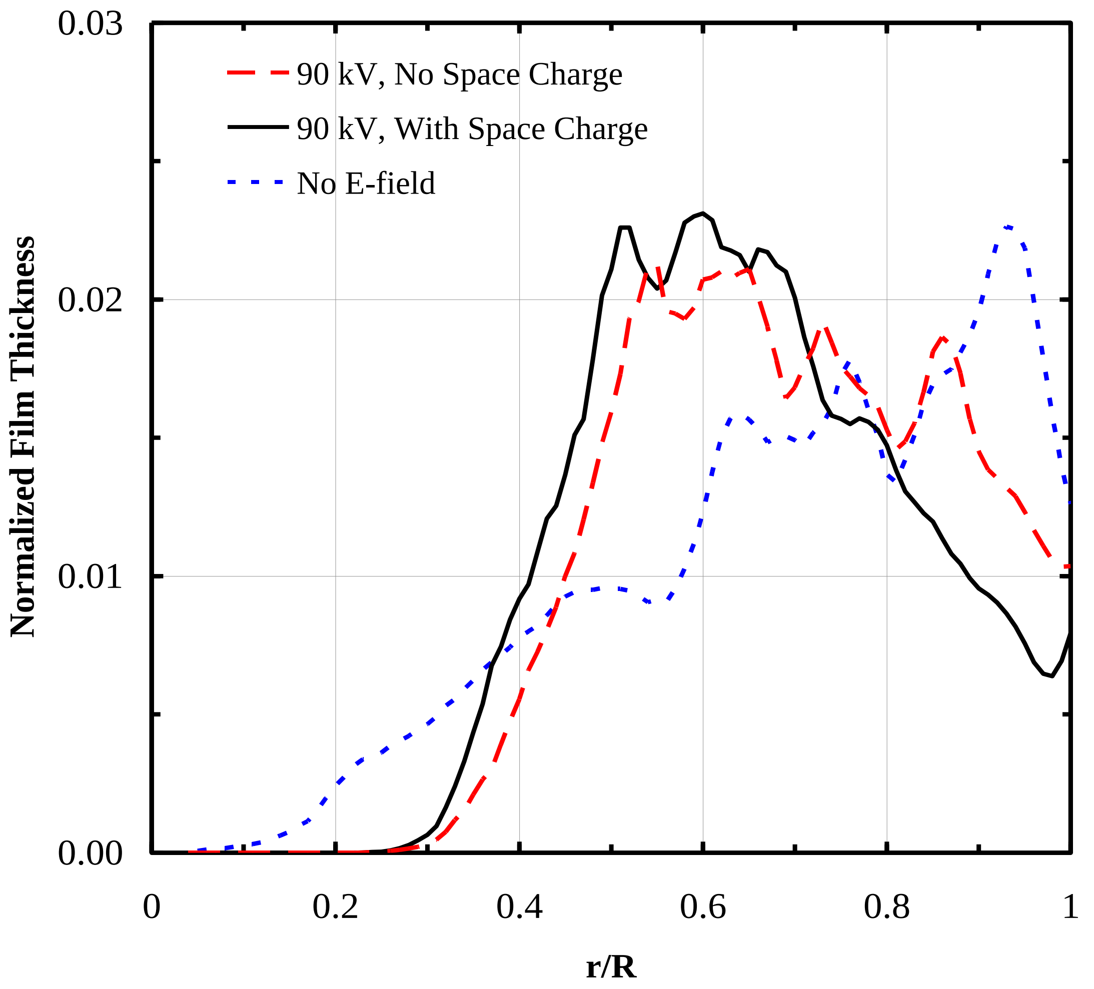


90 kV, with space



Film thickness effects the evaporation rate and hence turn-around time

Averaged "Wet" Film Thickness on Target



Summary

- High-fidelity models can accurately capture the physics behind the effectiveness of the cleaning and disinfecting solutions being explored by the airline industry.
- Simulations can lower the cycle time; reduced costs associated with the physical tests and expand the design space.
- Design effectiveness can be accurately captured by physics-based simulations.
- Ansys simulation software provide designers and analysts with an integrated platform to perform end-to-end component and system level analysis and arrive at the optimal solution.

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Thank you

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https://www.ansys.com/about-ansys/covid-19-simulation-insights

Ansys