

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

Presented by  
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## Contributors

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**Aleksandra Egelja-Maruszewki, PhD**



# Technical panel



**Valerio Viti, PhD**  
Aerospace and Defense Industry Lead,  
Ansys, Inc.



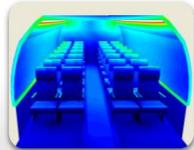
**Kishor Ramaswamy**  
Manager Application Engineer,  
Ansys, Inc.

# Webinar outline

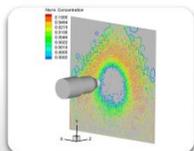
- Introduction
  - Coronavirus: the basics
- The Ansys solution to help reduce the spread
- Airliner cabin case studies:



Cabin HVAC system studies



Disinfection of cabin surfaces and HVAC air via UV light



Disinfection of cabin via electrostatic sprays

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**Ansys**

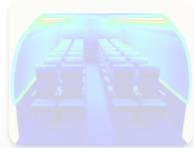
**Ansys**

# Webinar outline

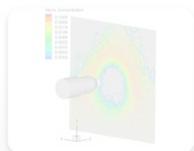
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# Coronavirus – A Highly Contagious Airborne Disease

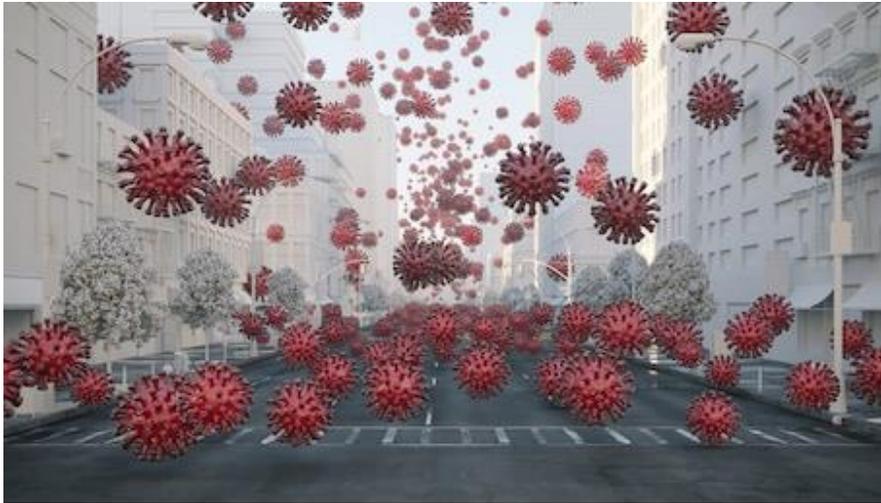
- The current global pandemic caused by COVID-19 has impacted people around the world and has caused many industries to come to a halt due to the risks of transmission.
- One key reason for the pandemic is the highly contagious nature of the virus particles. The three
  - Airborne
  - Droplets
  - Touching
- Air travel in particular has been greatly affected by the pandemic because of:
  - close proximity of passengers in an enclosed environment and
  - the relatively long duration of flights

**Develop best-practices and solutions for new-normal**



# Multiple solutions will be 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



HVAC in transportation systems will need to be studied and optimized



Surface disinfection via mobile or installed UV systems or sprays

# Multiple solutions will be 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

## 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.

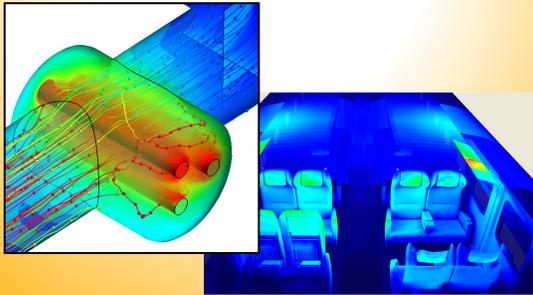
HVAC systems in public spaces will need to be studied and optimized

Surface disinfection via mobile or installed UV systems or sprays

# Anslys solution for pathogens neutralization in an enclosed environment

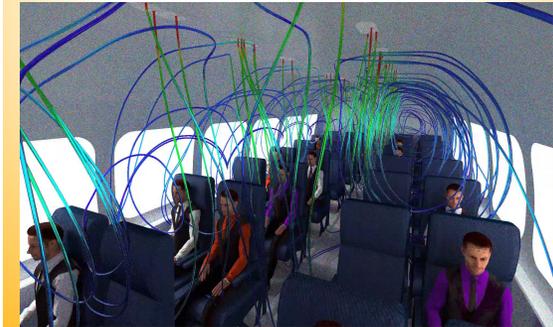
## UV Sterilization

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



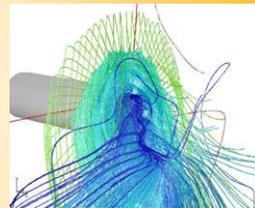
## Cabin HVAC System

- Analyze flow patterns
- 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 effect

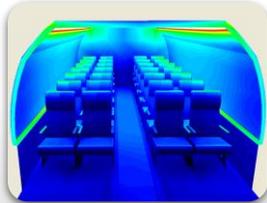
- Cough/sneeze droplets suppression
- Detail deposition pattern
- Dispersion



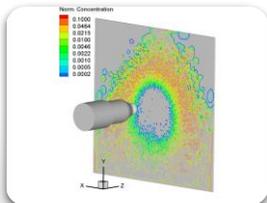
# Case studies



Cabin HVAC system studies



Disinfection of cabin surfaces and HVAC air via UV light

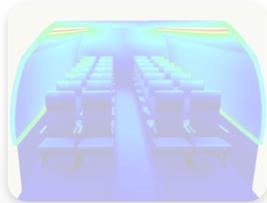


Disinfection of cabin via electrostatic sprays

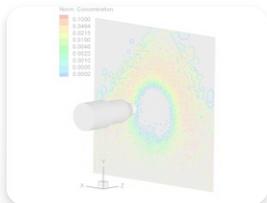
# Case studies



Cabin HVAC system studies

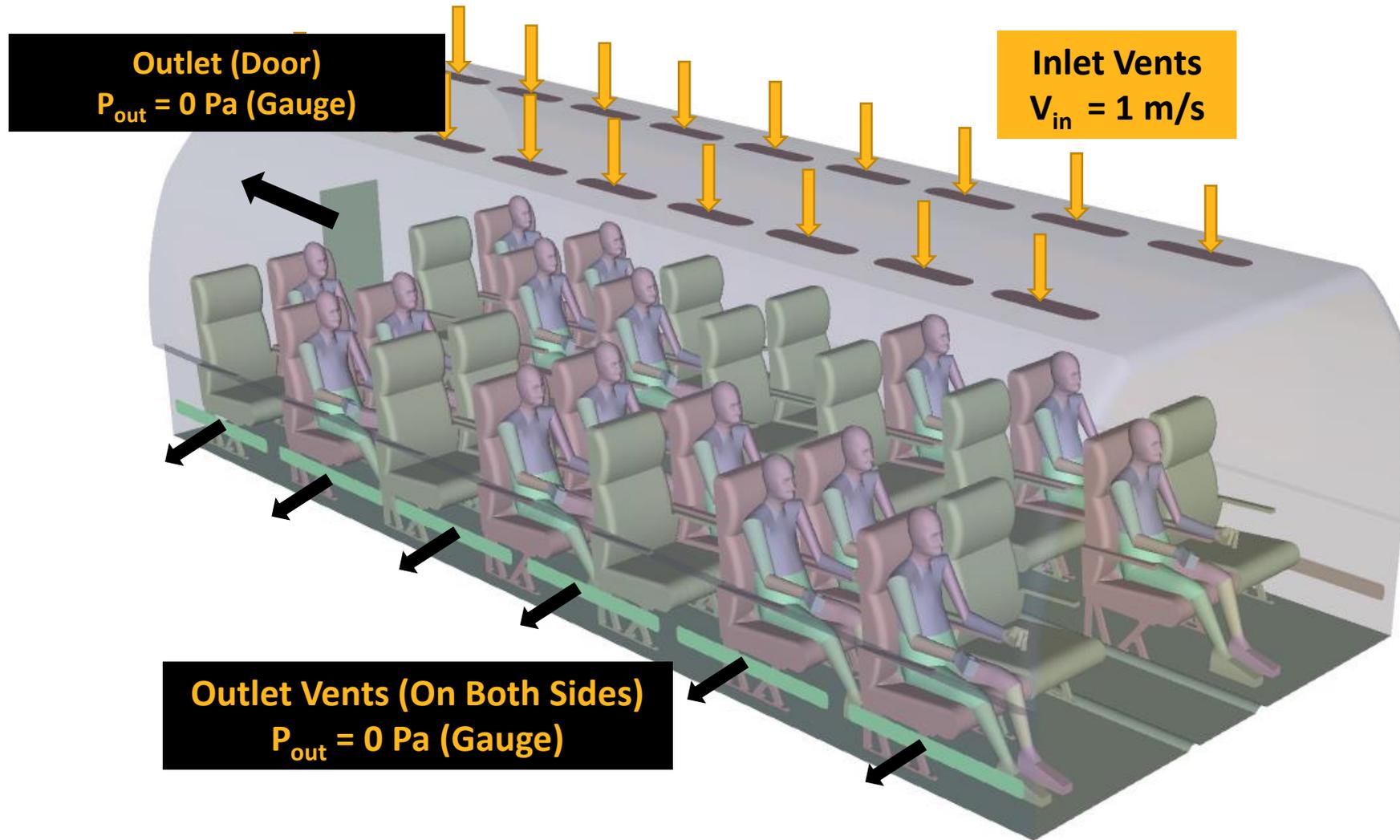


Disinfection of cabin surfaces and HVAC air via UV light



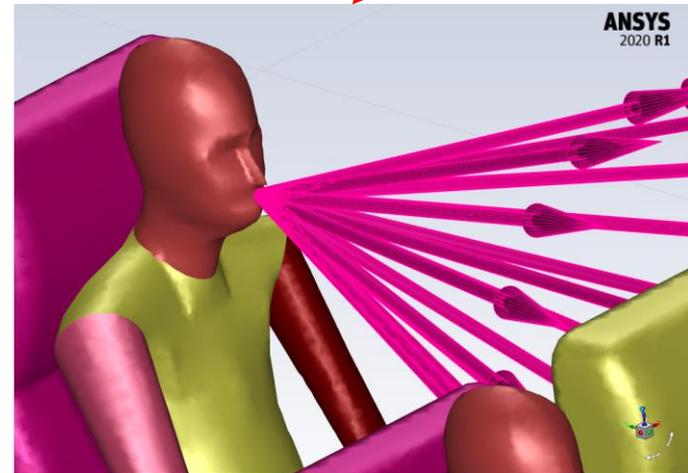
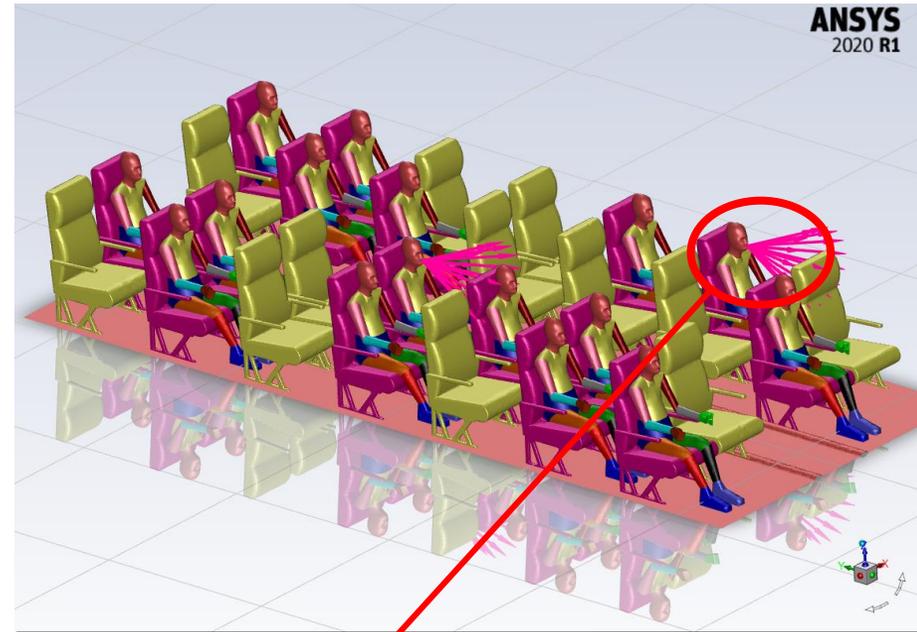
Disinfection of cabin via electrostatic sprays

# Example of problem setup for CFD analysis: air cabin



# Case 1: cough simulation without masks

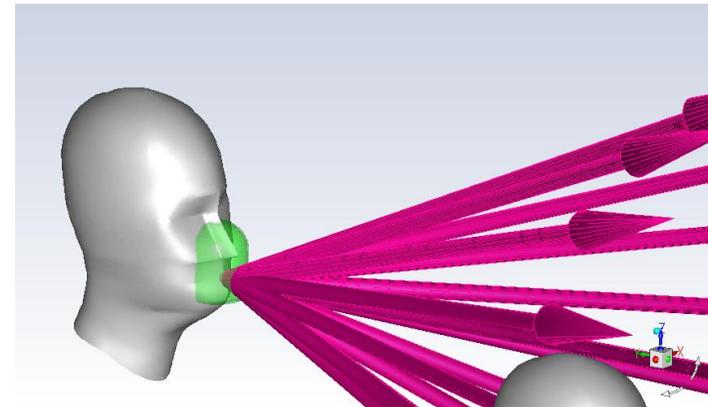
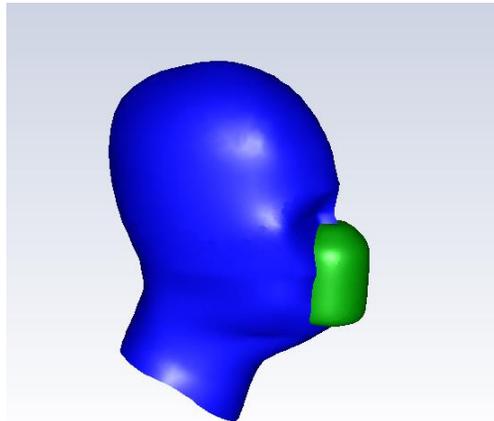
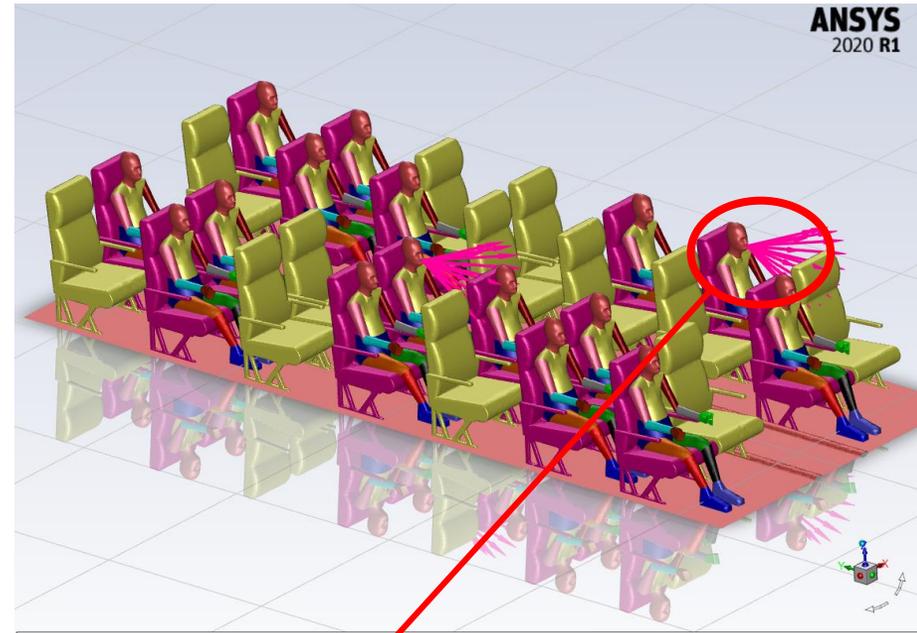
- Simulation set up with two people coughing in the cabin
- Cough times are staggered
- Coughing parameters are same for both the coughs
  - Rosin Rammler droplet size distribution with a min size:  $2 \mu m$ , max size:  $75 \mu m$ , mean size:  $20 \mu m$
  - Cough velocity: 11m/s directed straight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

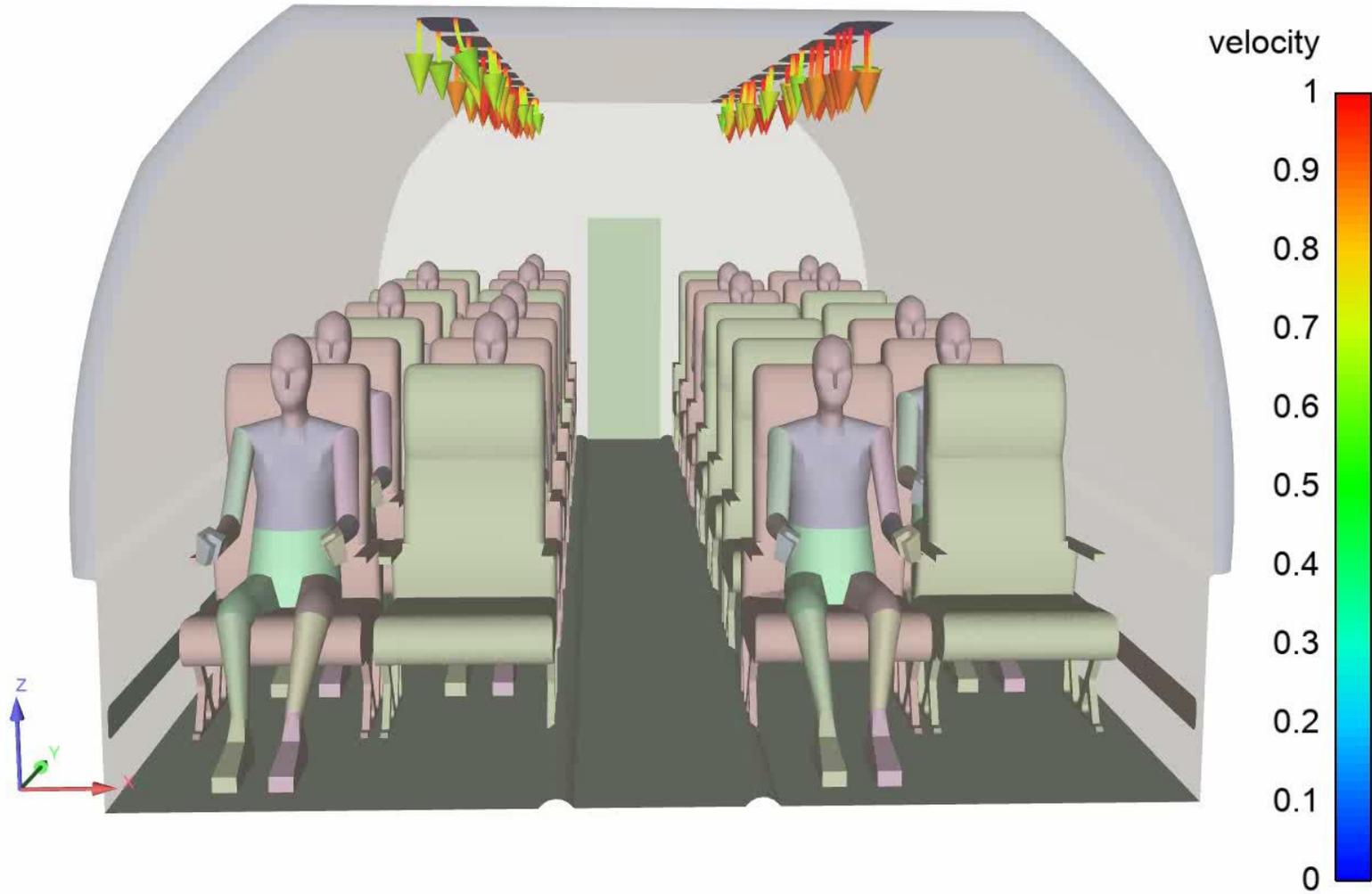
## Case 2: cough simulation with mask

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

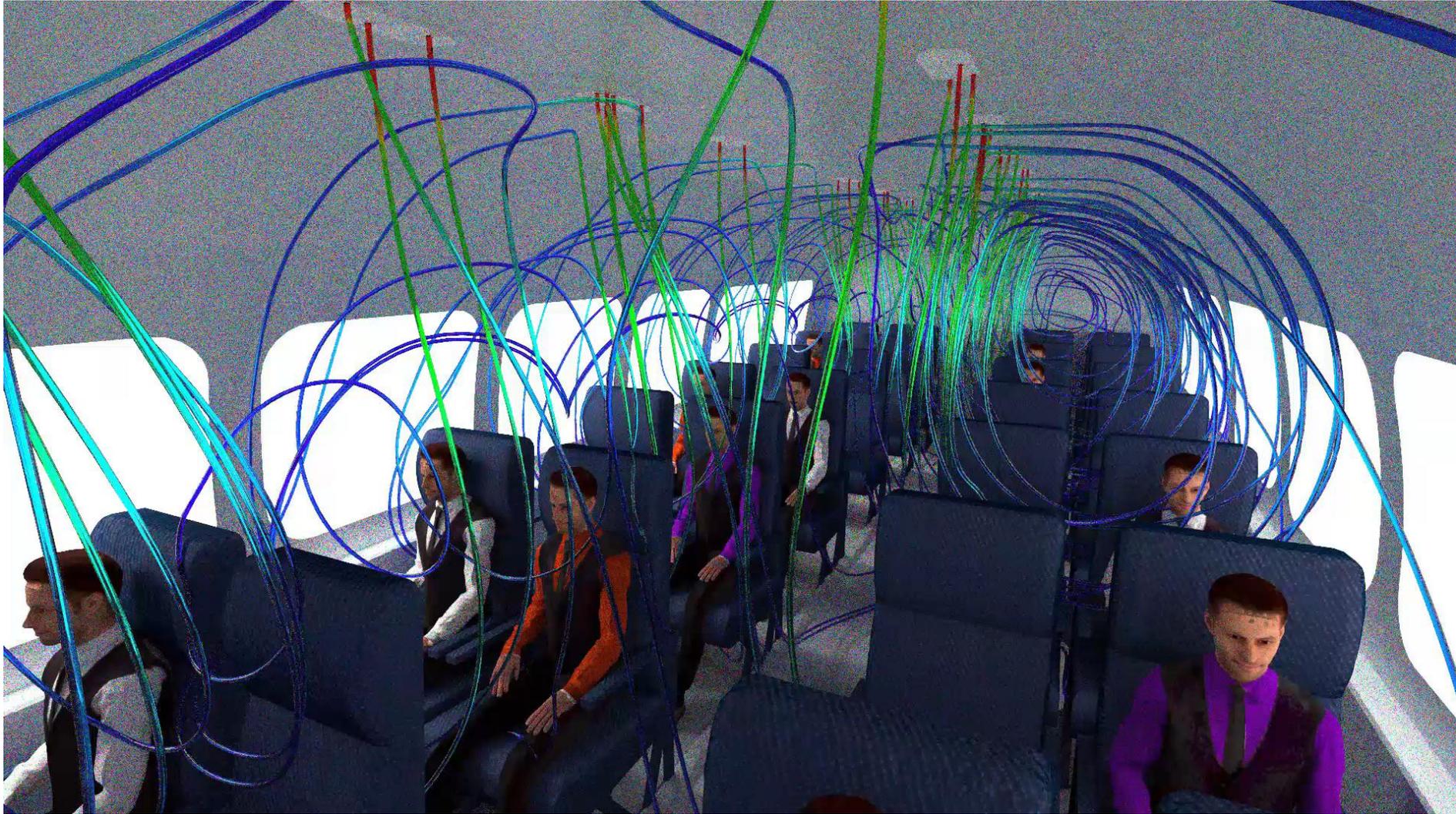


Ref: Bourouiba, L., Dehandschoewercker, E., & Bush, J. (2014). Violent expiratory events: On coughing and sneezing. *Journal of Fluid Mechanics*, 745, 537-563. doi:10.1017/jfm.2014.88  
Vivek Kumar, et al., On the utility of cloth facemasks for controlling ejecta during respiratory events., arXiv: Medical Physics, 2020.

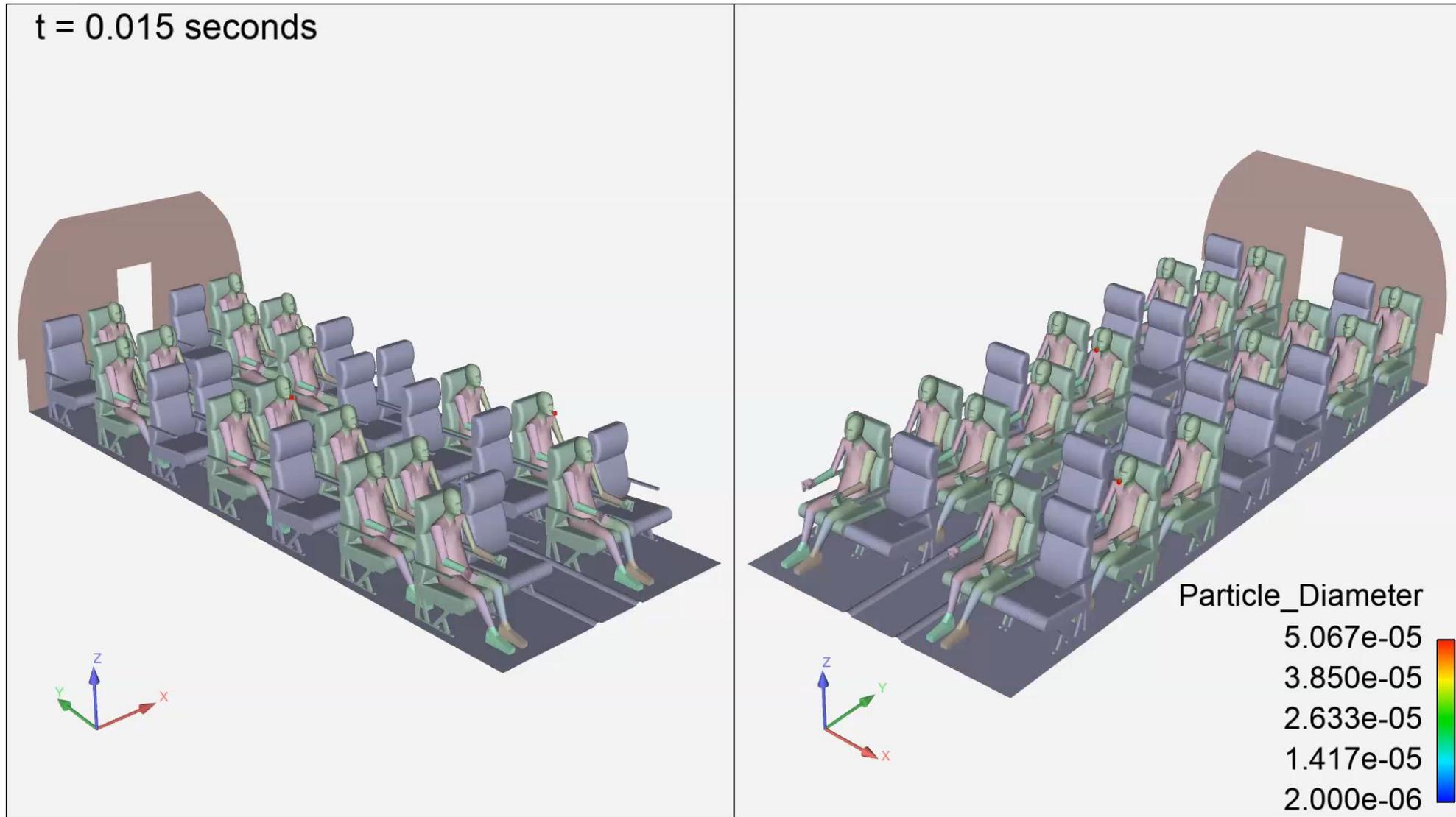
# Animation: Streamlines



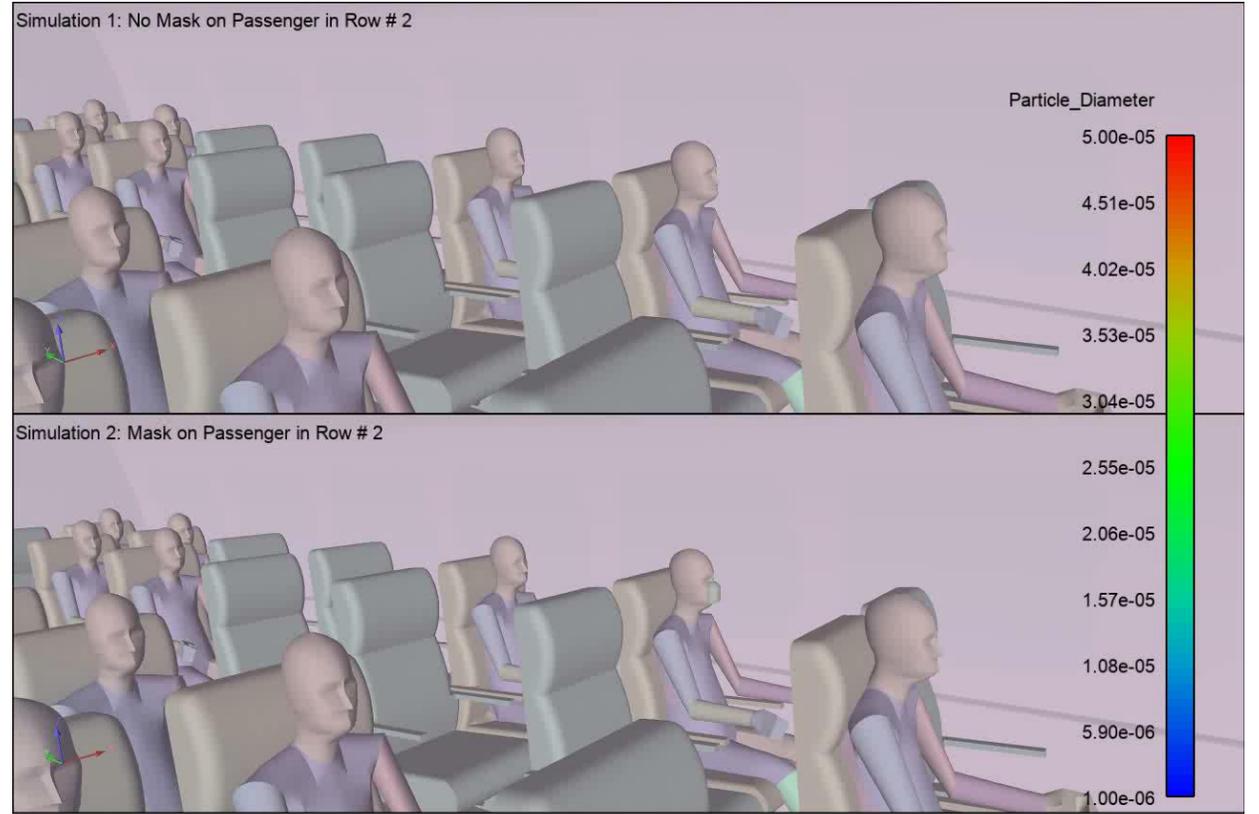
# Analysis of airliner cabin HVAC system: air patterns only



# Analysis of airliner cabin HVAC system: coughing without mask



# Analysis of airliner cabin HVAC system: coughing with mask



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

# Effect of pathogen spread with and without masks

No masks worn, 2 passengers coughing



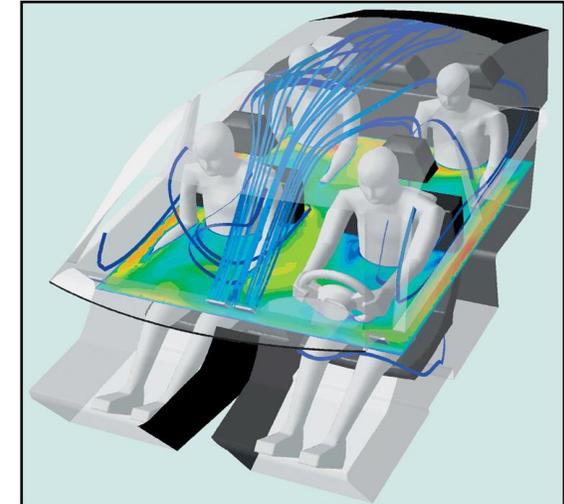
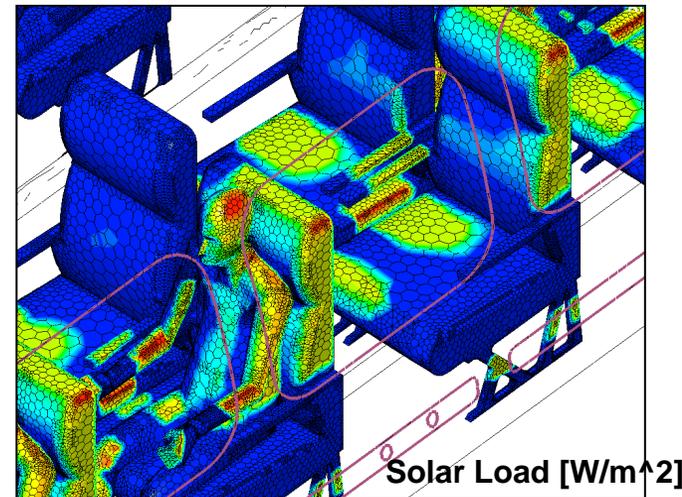
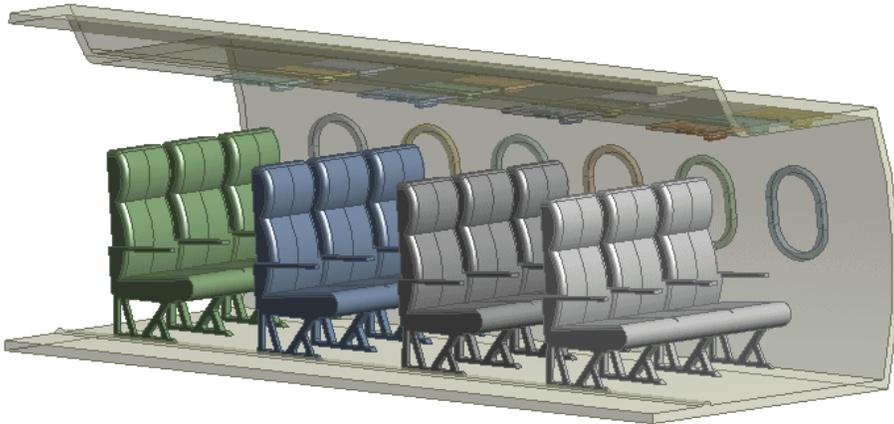
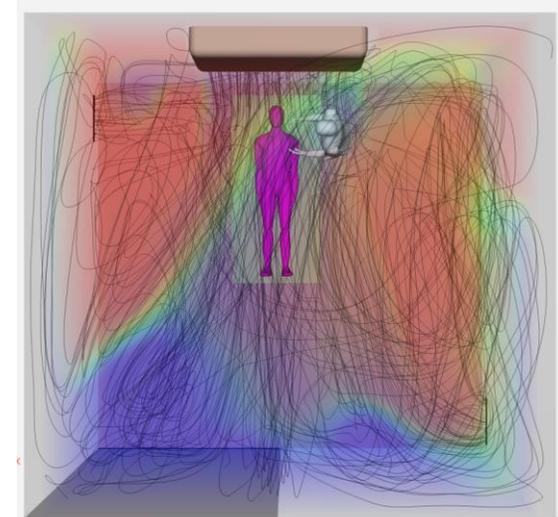
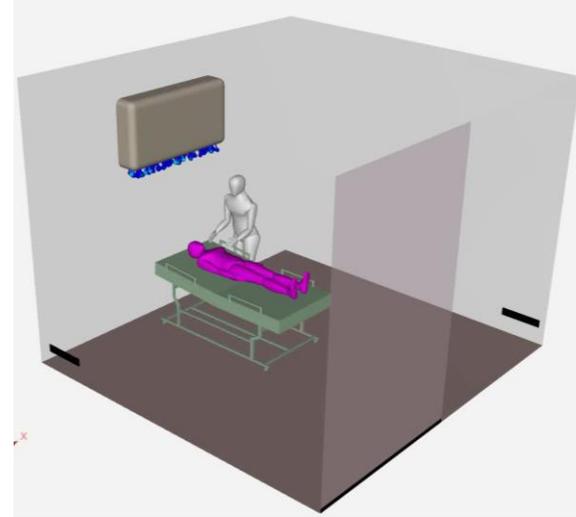
1 mask worn, 2 passengers coughing



Particle size x10 for person with mask for visualization purposes

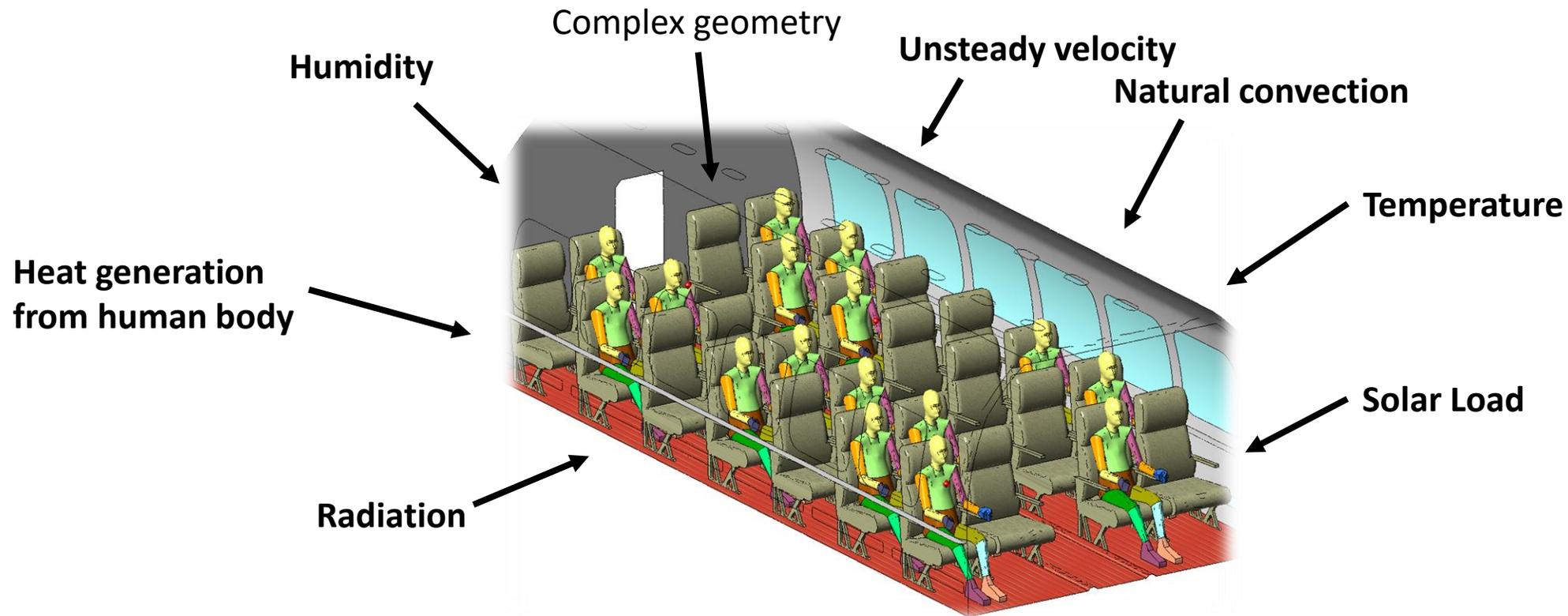
# Other modeling of HVAC systems and human comfort

- CFD can predict the comfort of occupants in closed environments such as:
  - aircraft
  - space capsule (low-gravity)
  - automobile
  - auditoriums
  - hospital rooms
- Key outputs from CFD simulation:
  - Velocity, Temperature, Humidity
  - Local Mean Age of Air / Ventilation Effectiveness
  - Predicted Mean Vote (PMV)
  - Predicted Percentage Dissatisfied (PPD)
  - Contaminant/Pollutant dispersion



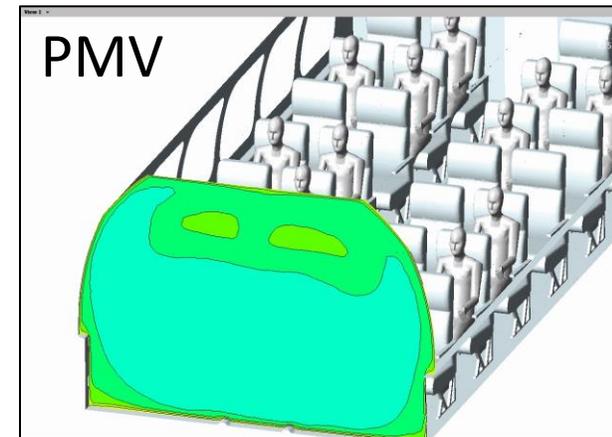
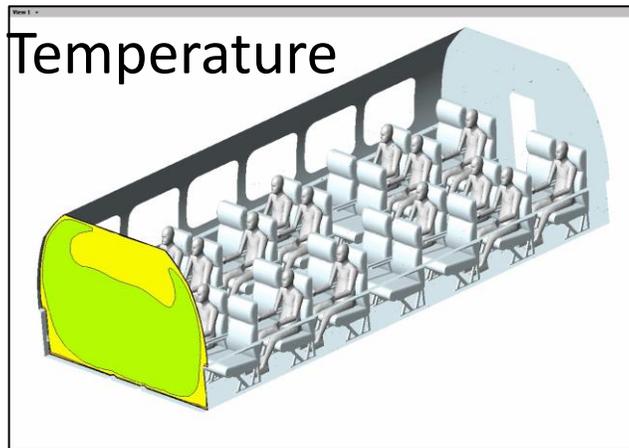
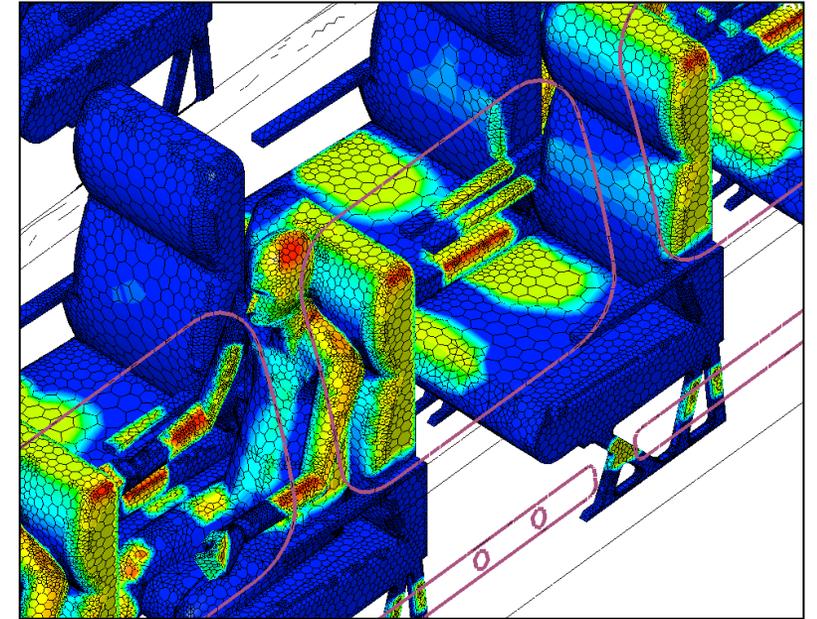
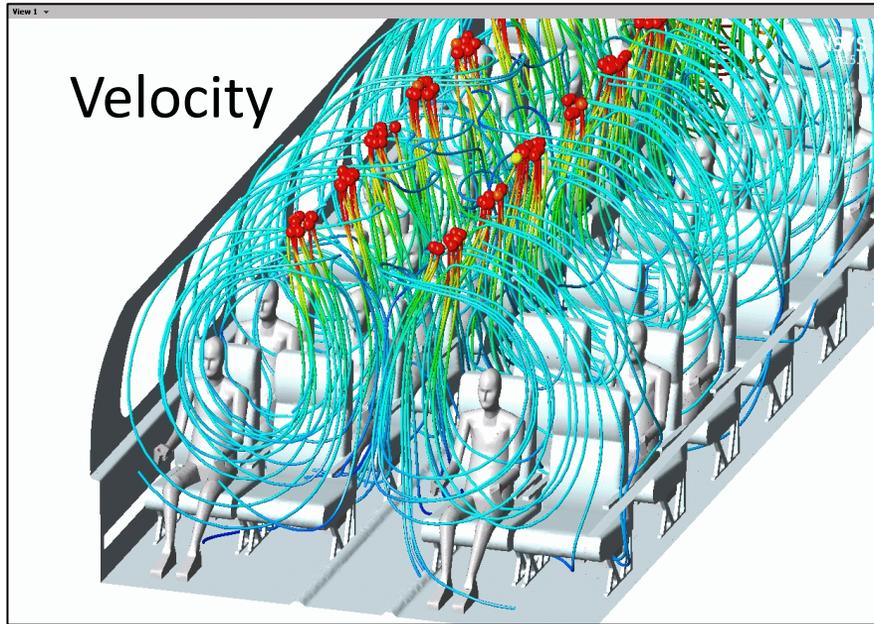
# System-level simulation of aircraft cabin: Ansys ROMs

- Reduce calculation costs for complex situations
  - Complex geometry : sheet, human body...
  - Unsteady simulation: heat up, cool down...
  - Non-linear physics: natural convection, radiation, humidity, solar load ...



# Example: Typical airliner cabin output

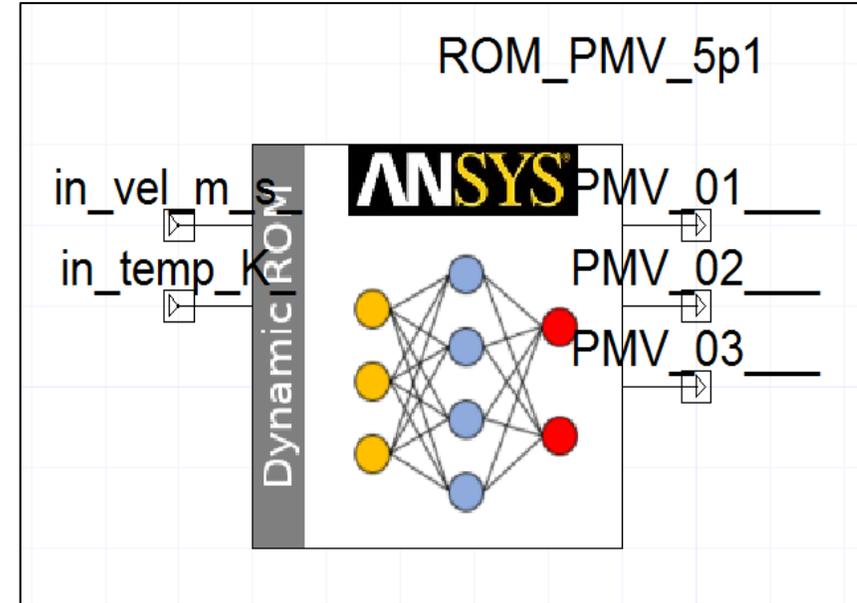
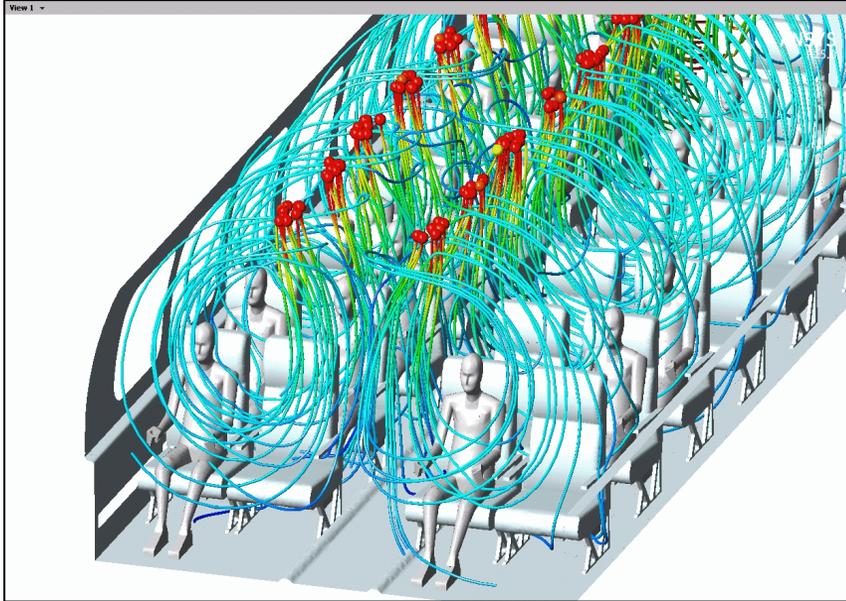
Solar Load[W/m<sup>2</sup>]



PMV is an index showing the thermal comfort. It is defined as a function of temperature, velocity, humidity and radiation.

# ANSYS ROM Technology

2 minutes unsteady simulation

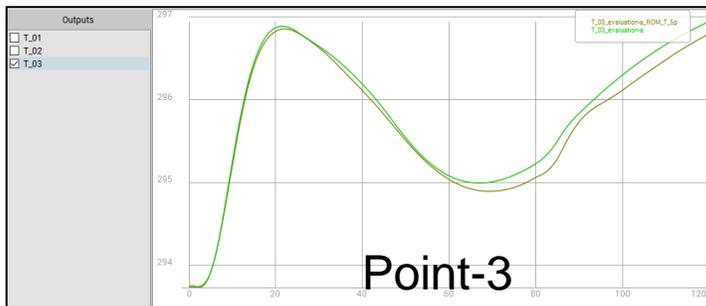
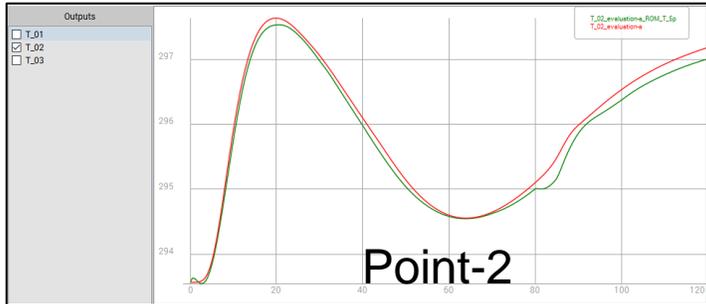
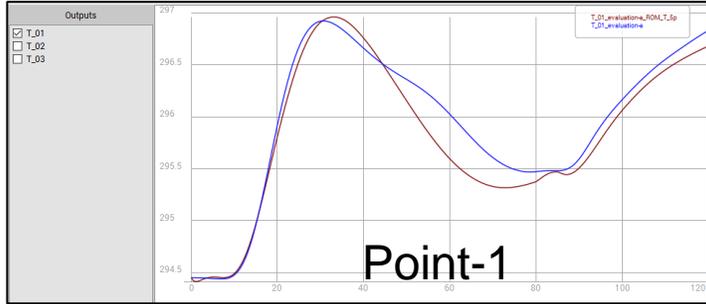


48hours@20 cores

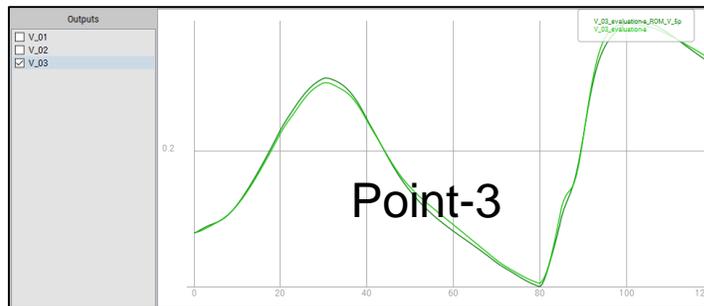
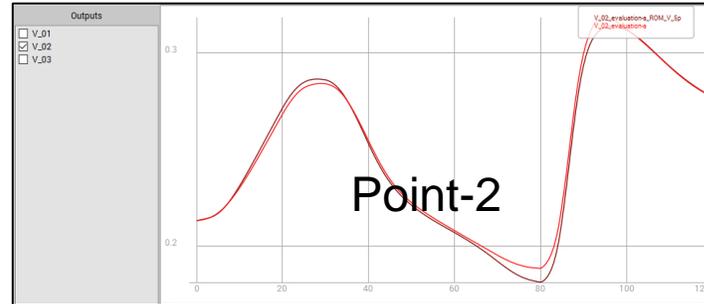
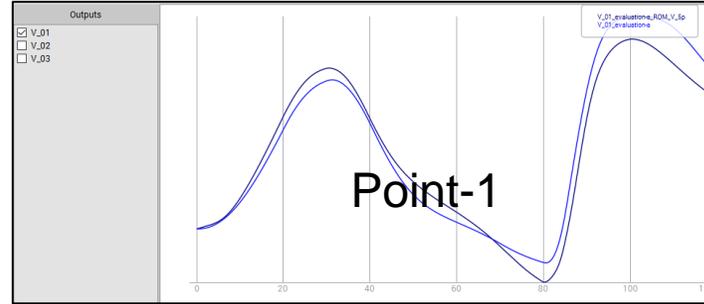
In a second

# Validation: prediction(ROM) vs. correct answer(Fluent)

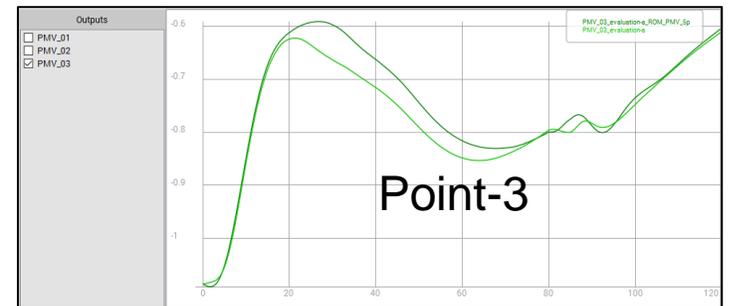
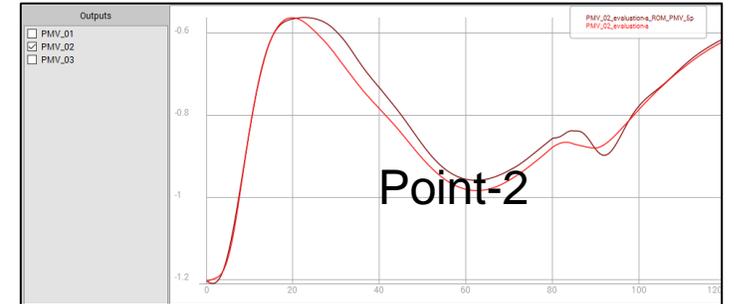
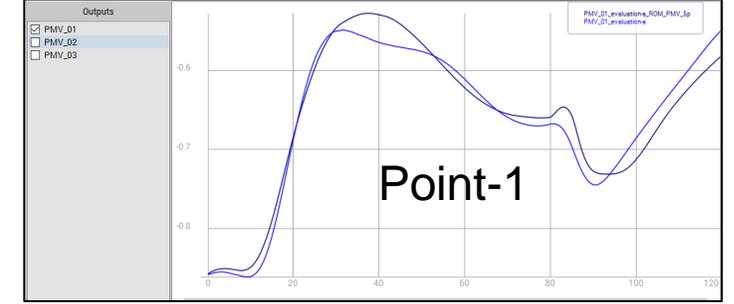
## Temperature



## Velocity



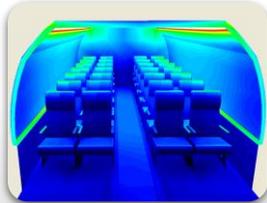
## PMV



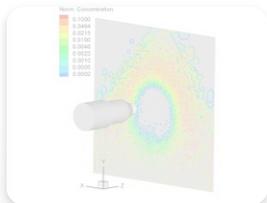
# Outline



Cabin HVAC system studies



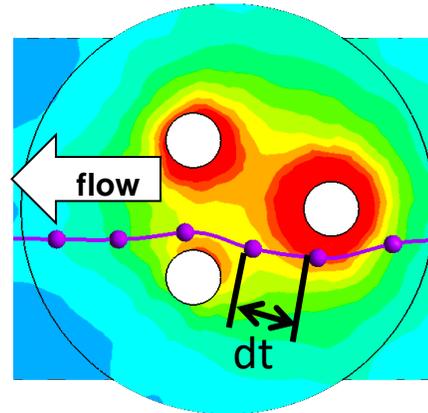
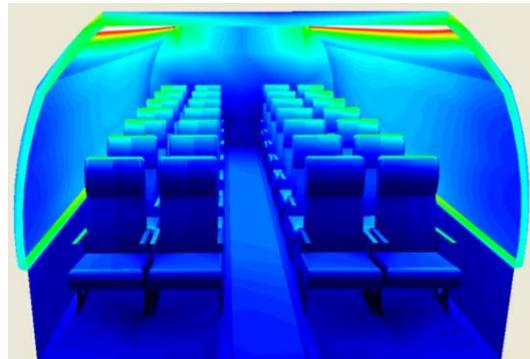
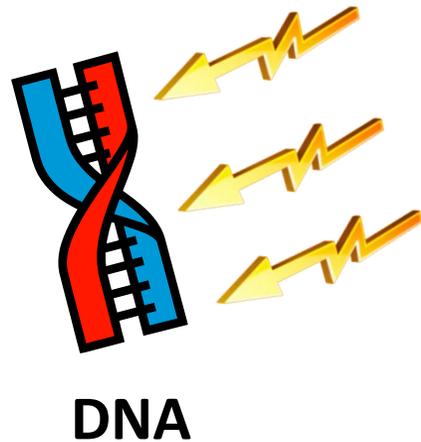
Disinfection of cabin surfaces and HVAC air via UV light



Disinfection of cabin via electrostatic sprays

# How to kill micro-organisms using UV light

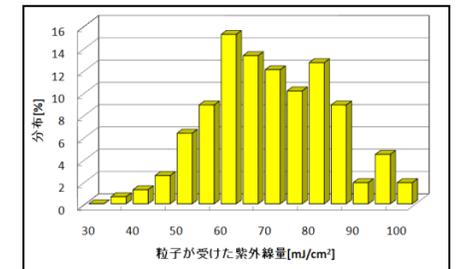
- Disinfection efficiency depends on:
  - Wavelength & Intensity: Lamp output
  - Exposure time: **design of disinfection system**



flow path of  
micro-organism

$$UV \text{ Dose} = \int_t (UV \text{ Intensity}) * dt$$

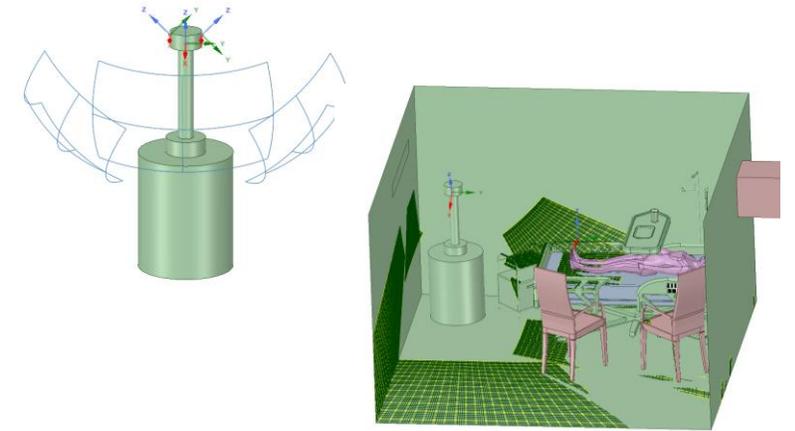
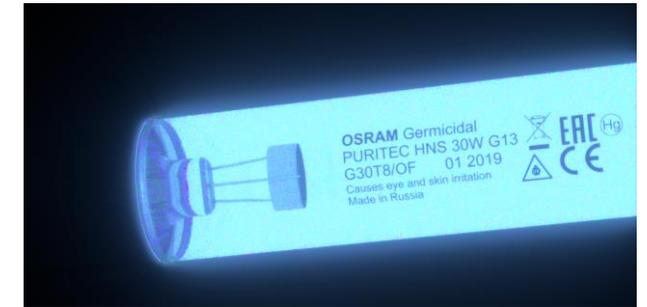
- Disinfection efficiency is defined as **“UV Dosage”**
  - UV Dosage**: Amount of received radiation in micro-organisms, either from continuous exposure or during the flow path in reactor



# Challenges for UV light surface disinfection systems

- Choosing the **optimal lighting system**
- Ensuring **complete exposure and irradiation** of all relevant surfaces including line of sight challenges
- Understanding the **dosage requirements**
- Optimizing the **design and motion of a mobile system**

Ansys / SPEOS





**Case study: UV Disinfection for  
transportation industry**

# / A Step by Step Workflow

1. Create 3D model of area under test (e.g. aero cabin)
2. Apply optical properties to all surfaces in the area
3. Define light delivery system
4. Define motion path *\*\* for mobile solution only*
5. Run simulations
6. Calculate cumulative irradiation on all relevant surfaces
7. Determine necessary exposure requirements (or speed requirements for mobile solution)
8. Verify that there are no missed surfaces

# Aero cabin case study

- **Three model comparisons**

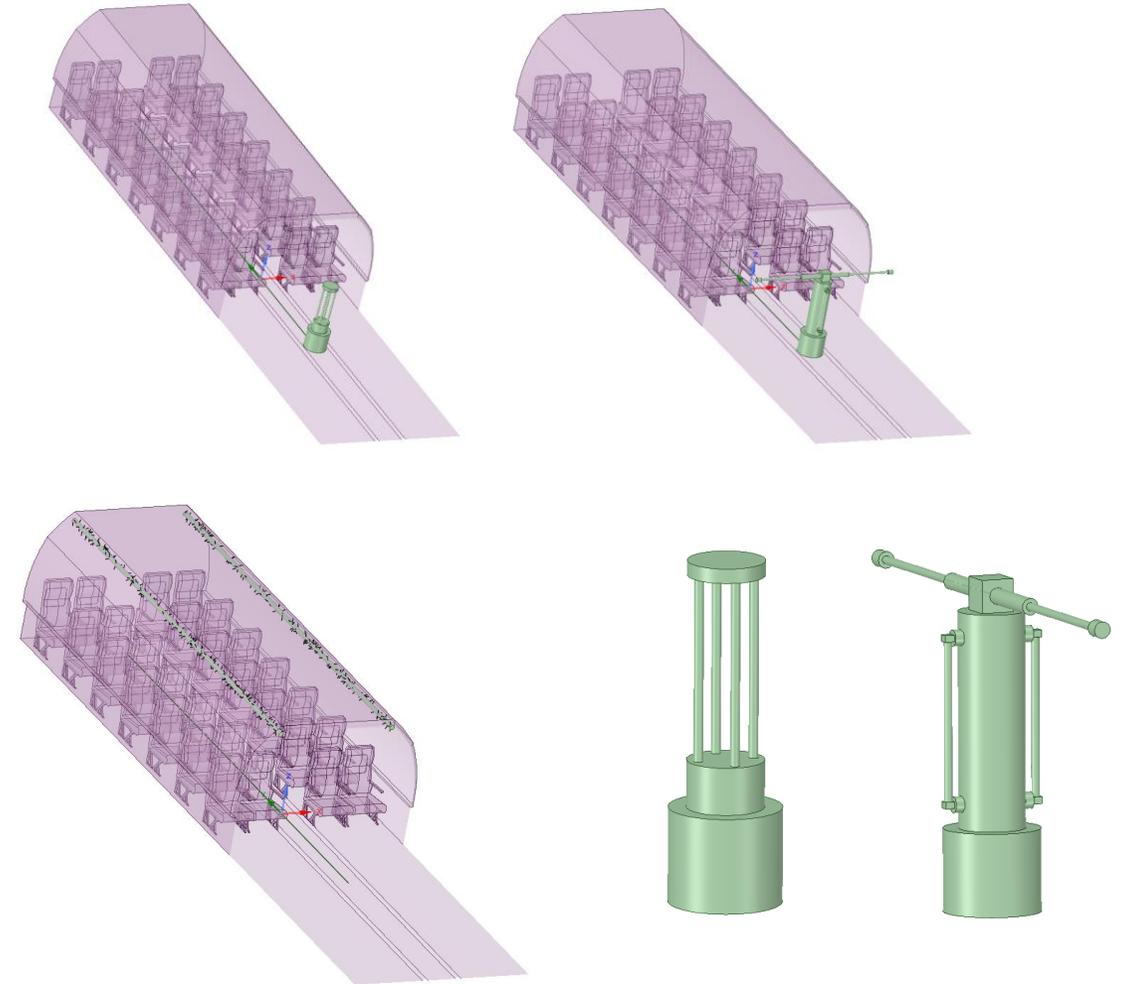
- Installed lights vs. two robot designs

- **Optical properties**

- Robot: ~80% reflectance
- Floor: ~50% reflectance
- Ceiling: ~80% reflectance
- Rest: ~40% reflectance

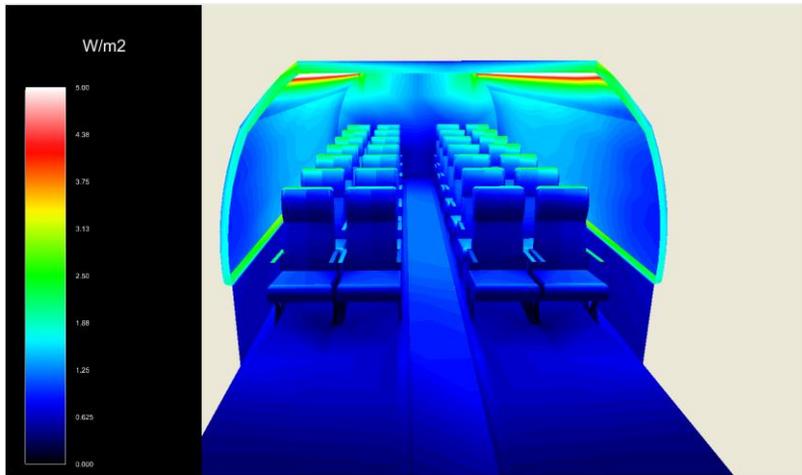
- **Light delivery system**

- Output power: 100W in all cases
- Intensity distribution: Lambertian
- Spectrum: Gaussian around 253.7nm

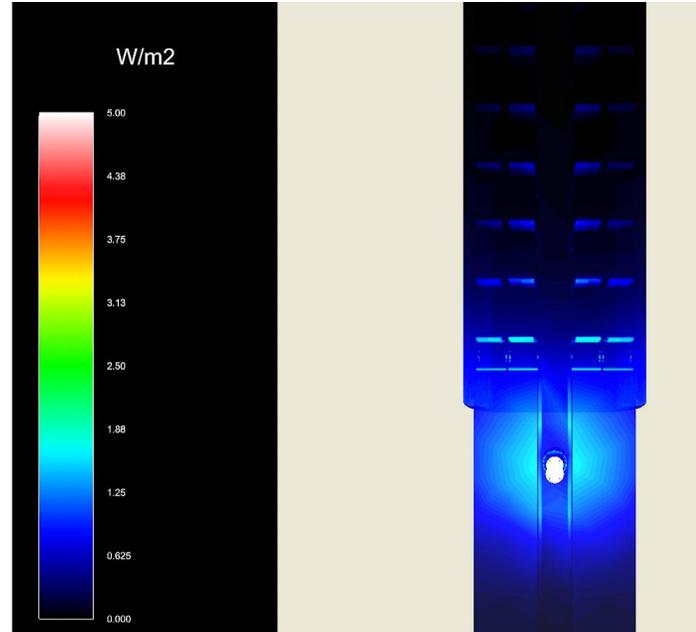


# Installed lights vs. Robot designs

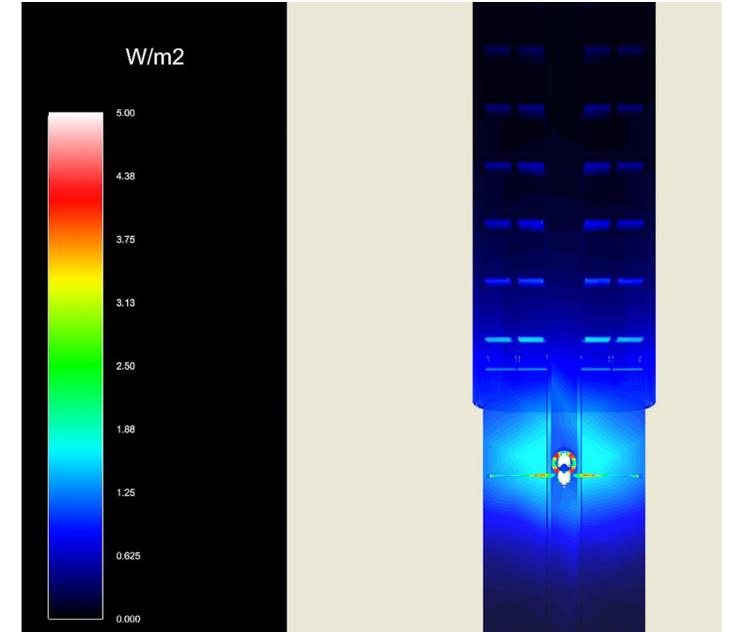
Installed lights



Robot design 1

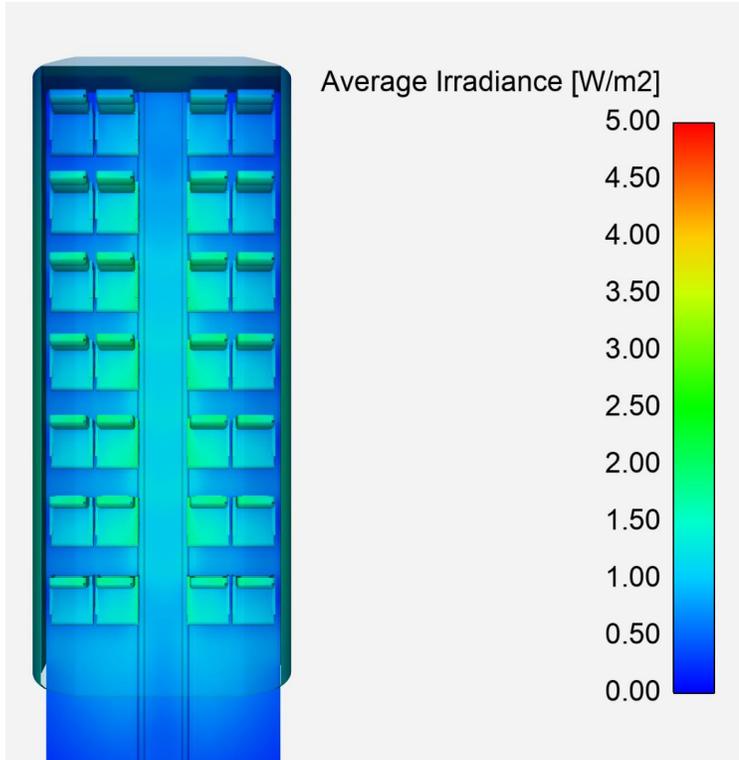


Robot design 2



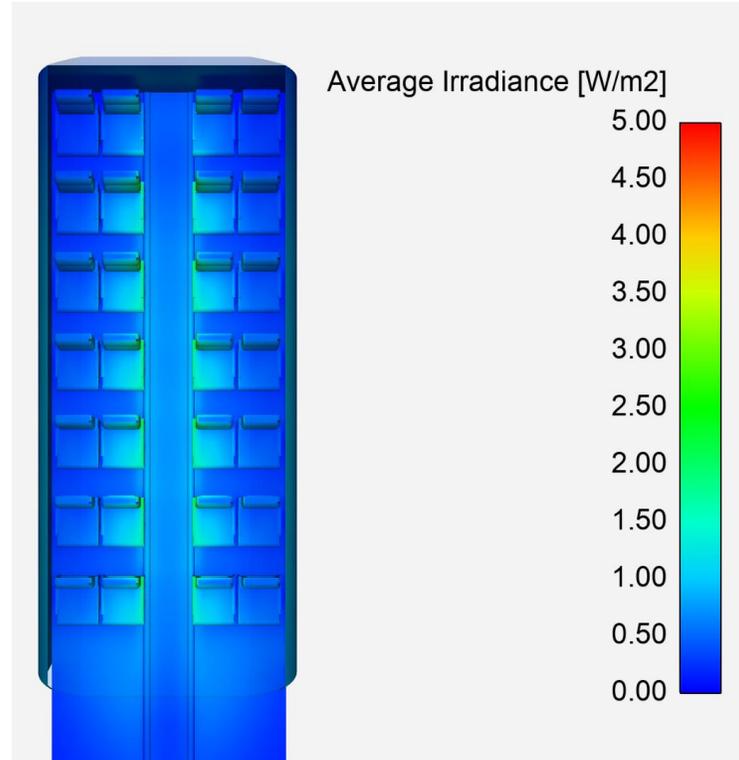
# Cumulative irradiation & dosage requirements

### Installed lights



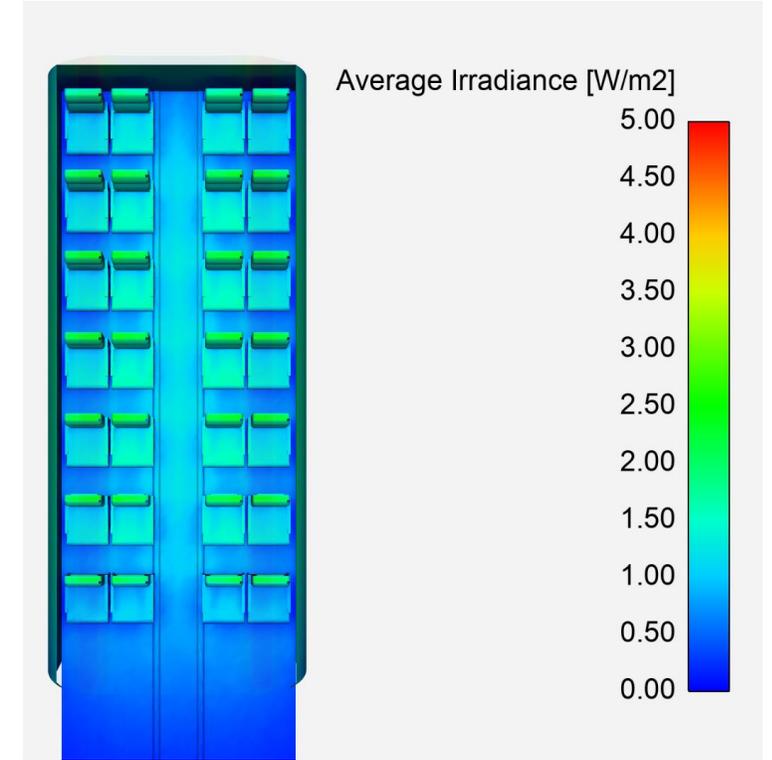
Lowest irradiance  
surface: ~4 uW/cm<sup>2</sup>

### Robot design 1



Lowest irradiance  
surface: ~1 uW/cm<sup>2</sup>

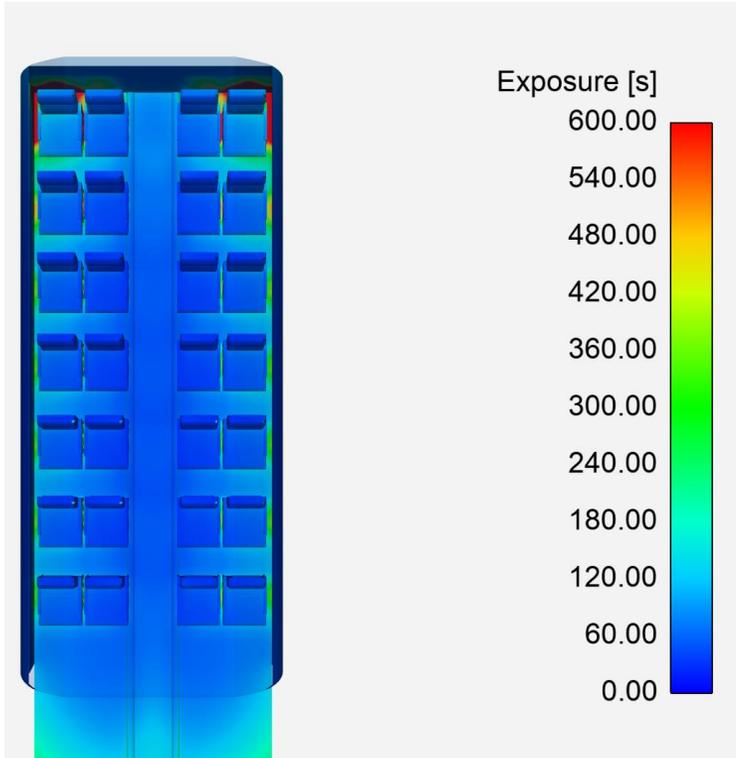
### Robot design 2



Lowest irradiance  
surface: ~6 uW/cm<sup>2</sup>

# Cumulative irradiation & dosage requirements

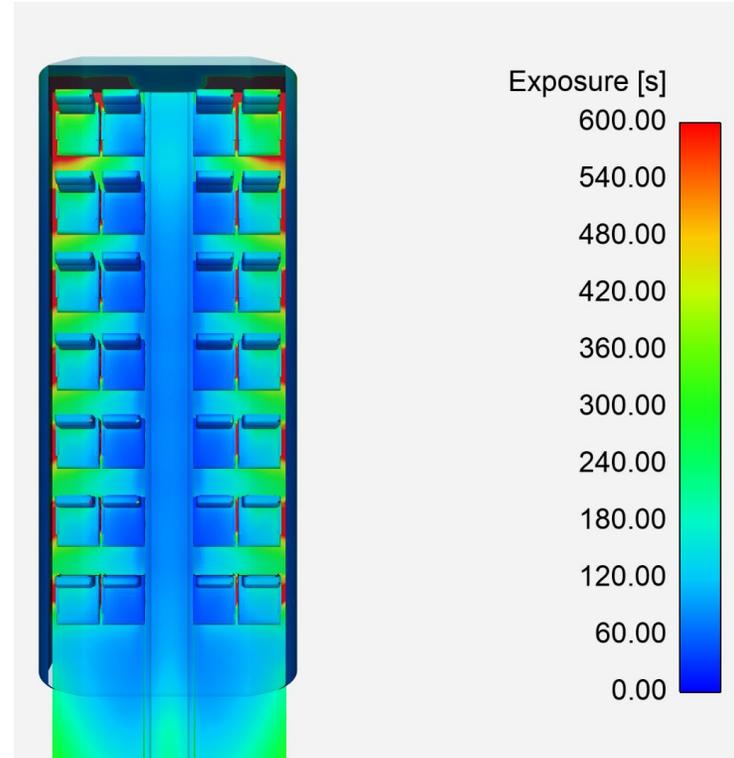
## Installed lights



**Exposure time required: 150s**

**Speed required: N/A**

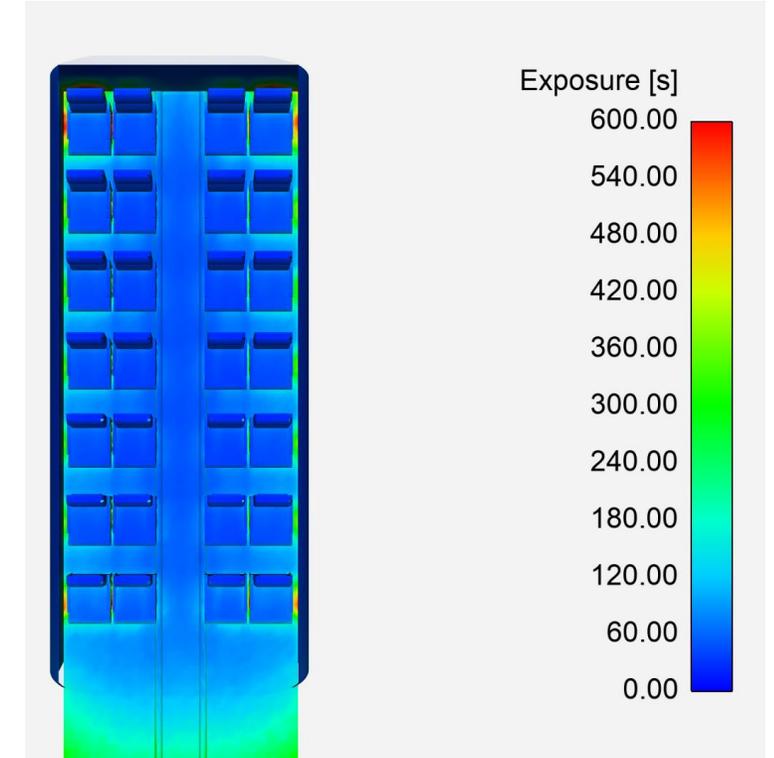
## Robot design 1



**Exposure time required: 600s**

**Speed required: 0.034 m/s**

## Robot design 2



**Exposure time required: 100s**

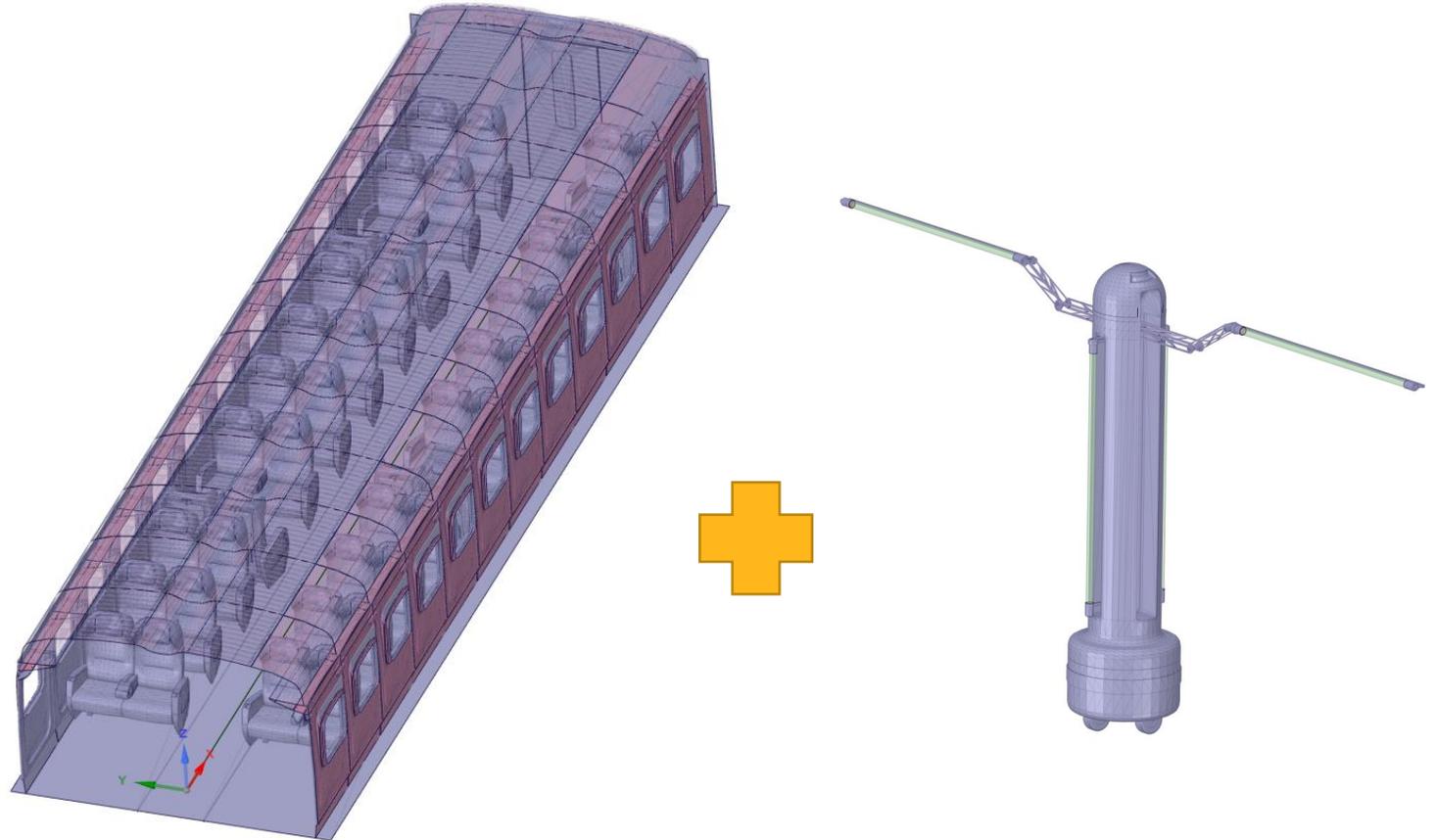
**Speed required: 0.204 m/s**

# / Aero cabin case study



# / Train cabin example

- **Moving to a new (but similar) environment, are we able to re-use the same robot design?**
  - ➔ Let's test through simulation, using the same model setup as for the aero cabin example
- **Optical properties**
  - Robot: ~80% reflectance
  - Floor: ~50% reflectance
  - Ceiling: ~80% reflectance
  - Rest: ~40% reflectance
- **Light delivery system**
  - Output power: 100W in all cases
  - Intensity distribution: Lambertian
  - Spectrum: Gaussian around 253.7nm



# / Train cabin example

UV-C light simulation for designing and deploying optimal surface disinfection



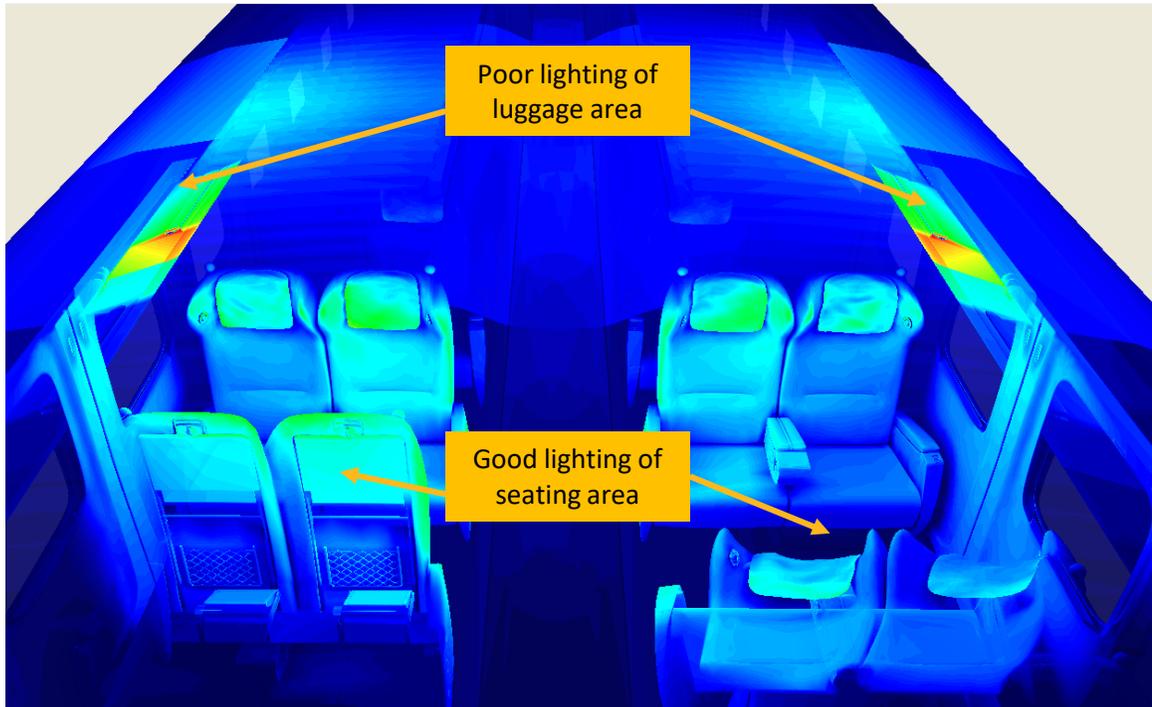
**Robot Model A**  
UV-C Neon Light ONLY

SIMULATED BY  
**Ansys**

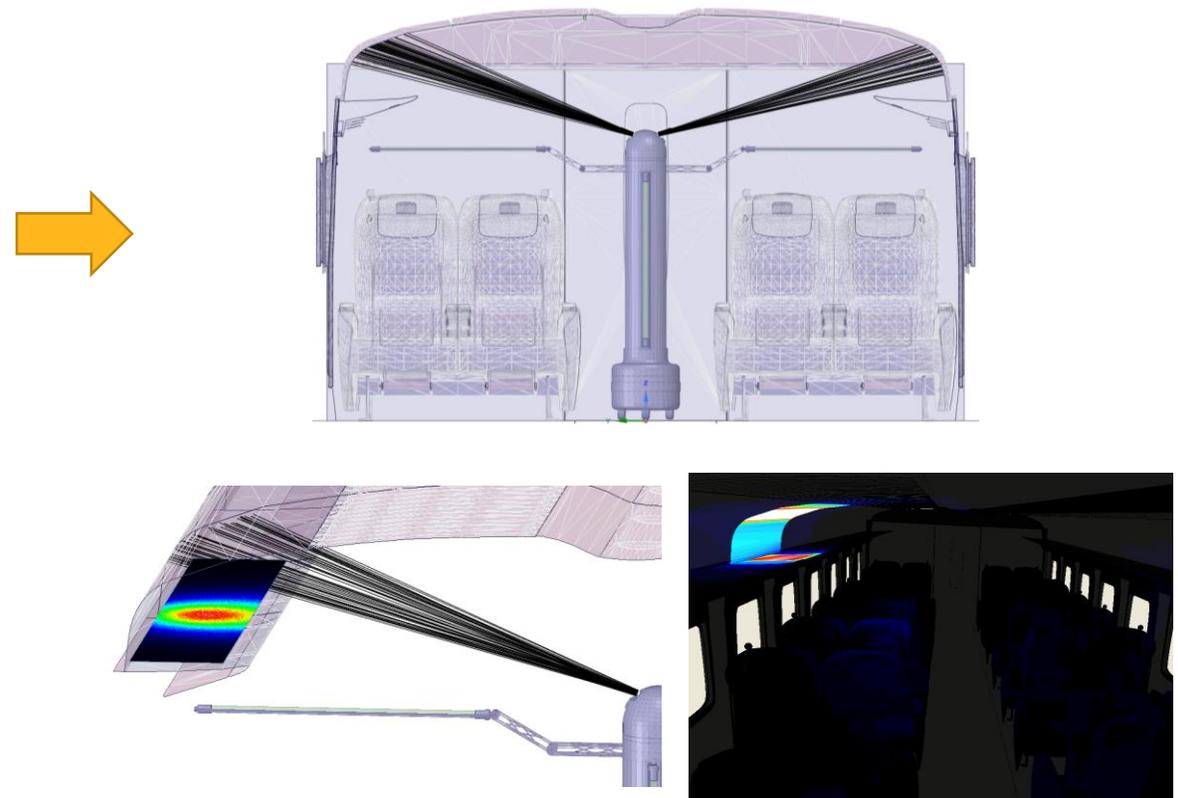
**Ansys**

# Train cabin example

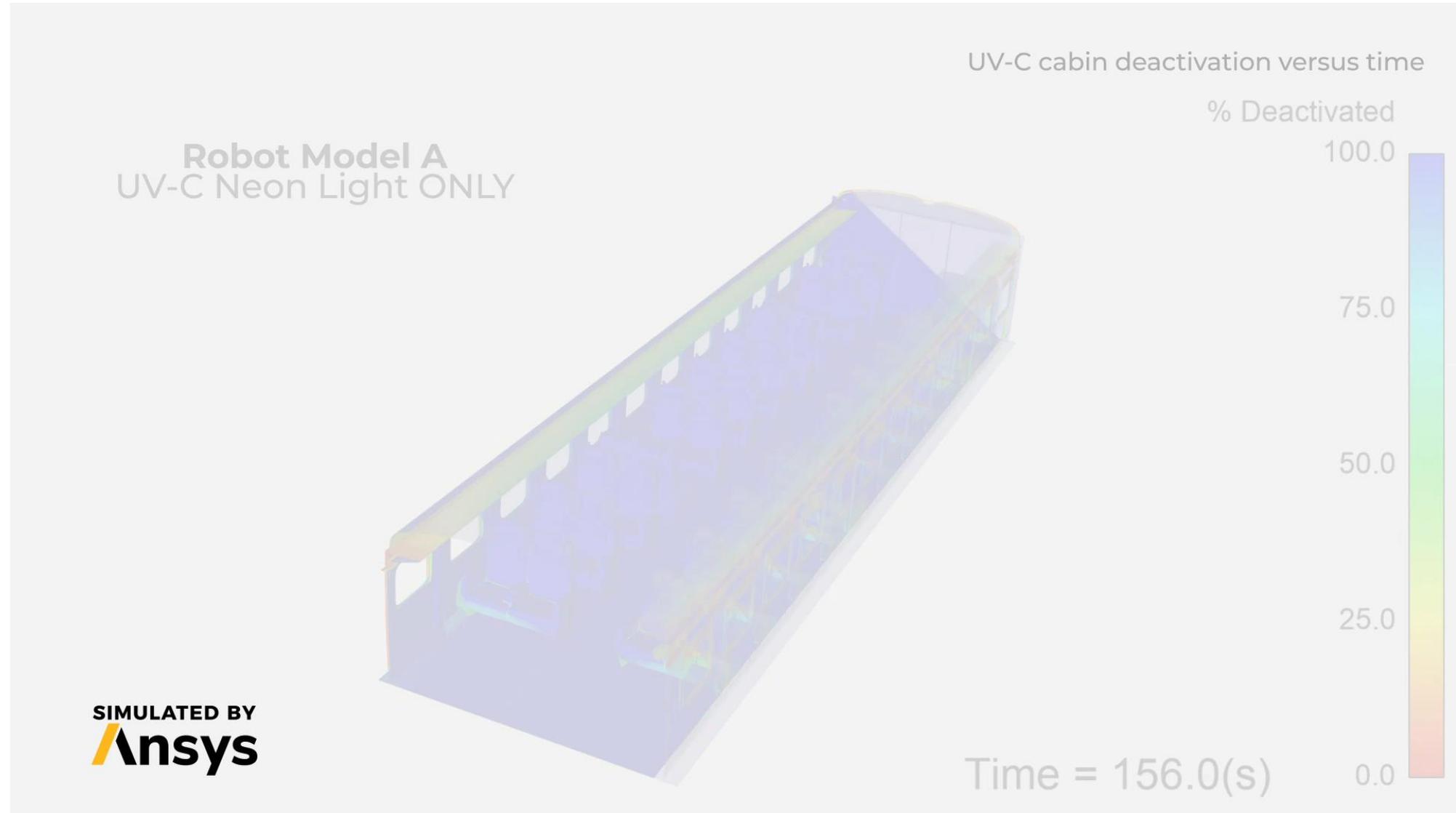
Original robot from airplane



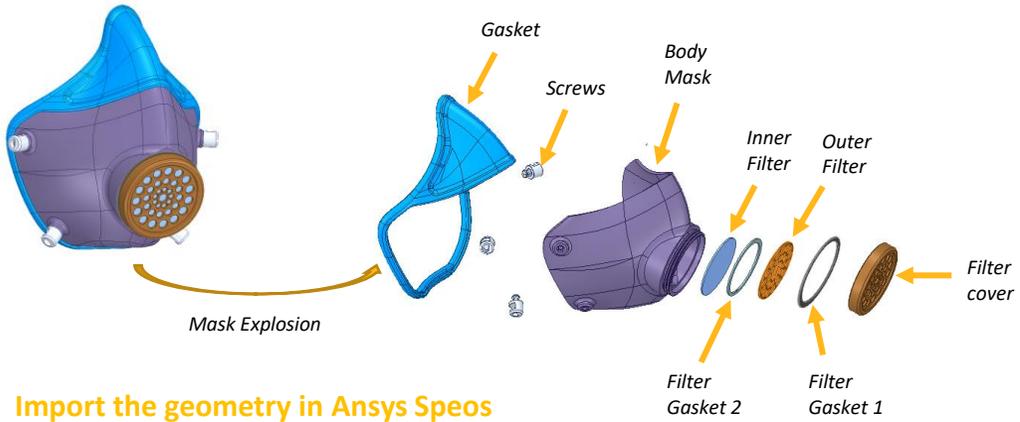
Modified robot with added LEDs



# / Train cabin example

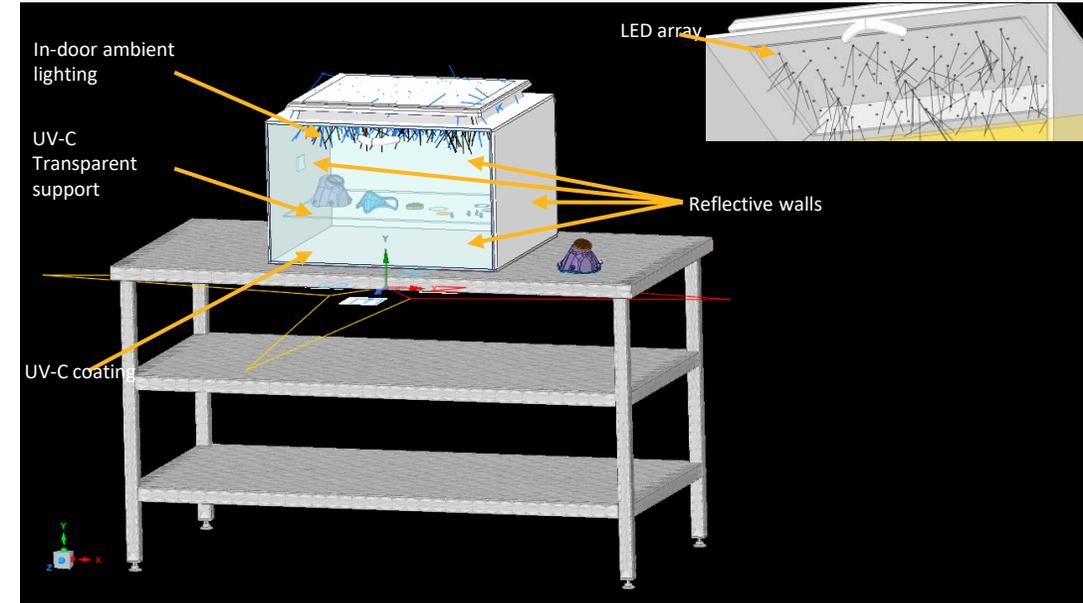
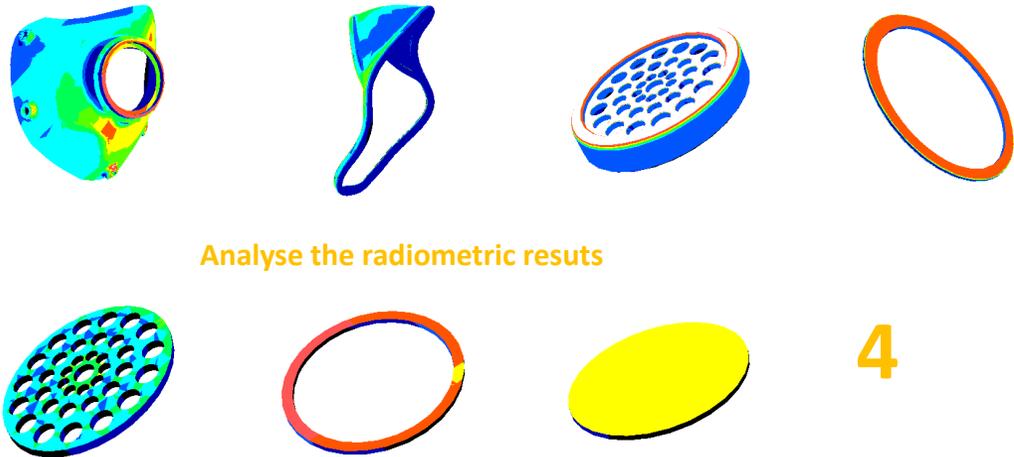


# Mask disinfection example

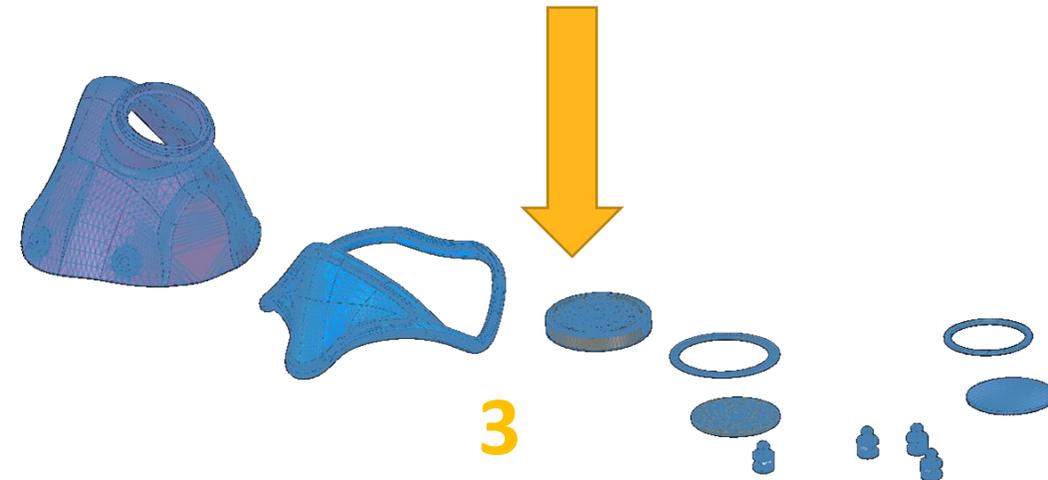


Import the geometry in Ansys Speos

1



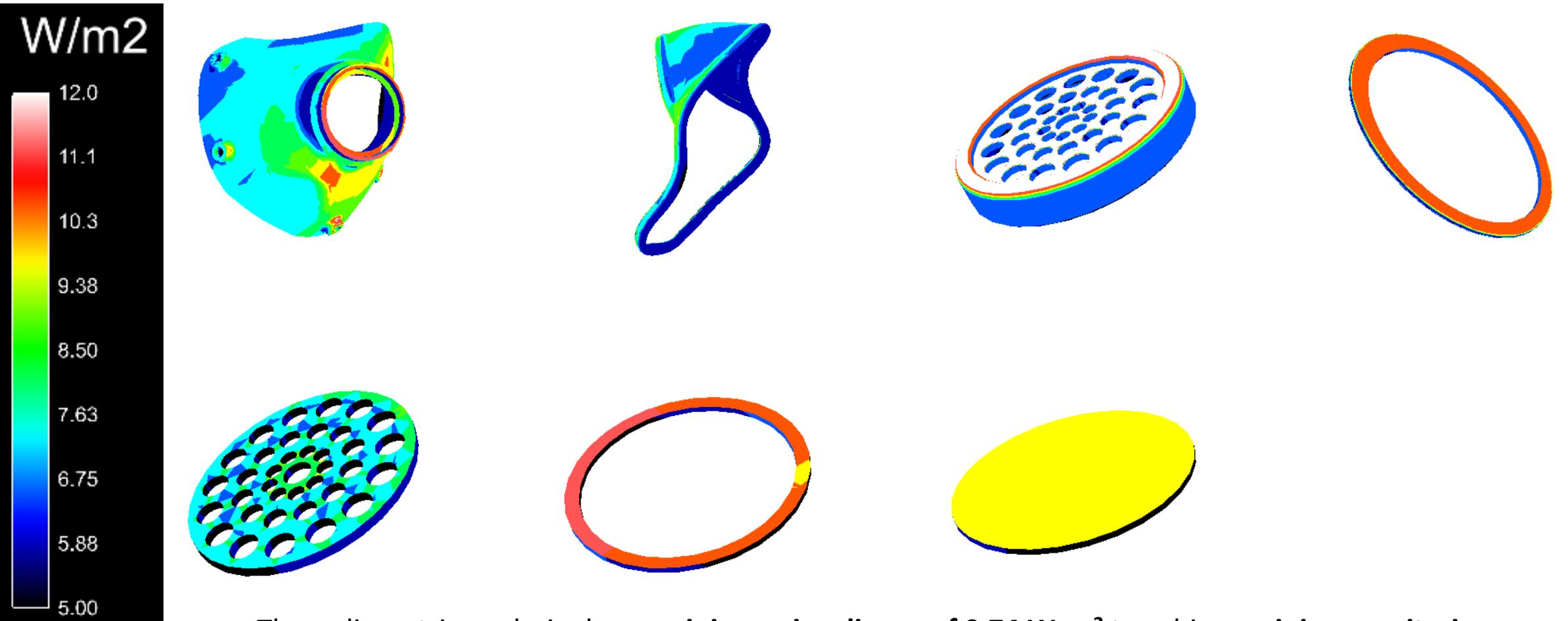
Define the materials properties and sources



Apply the 3D irradiance sensor on the Mask parts



# Mask disinfection example



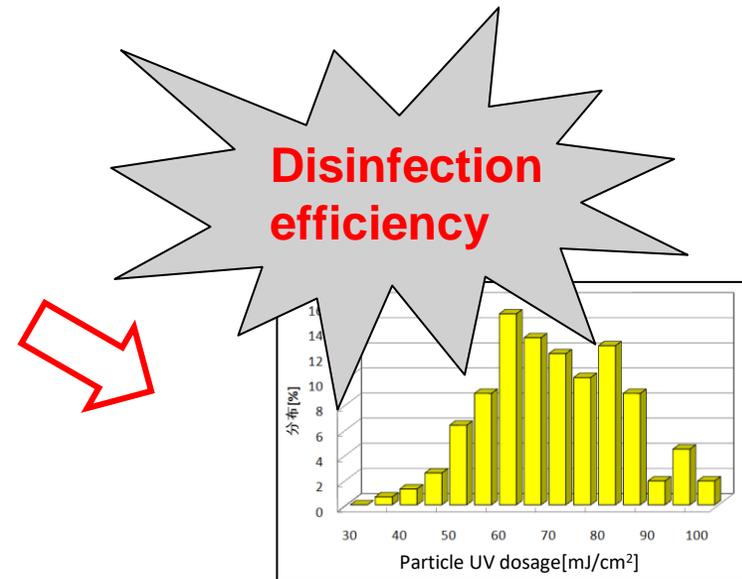
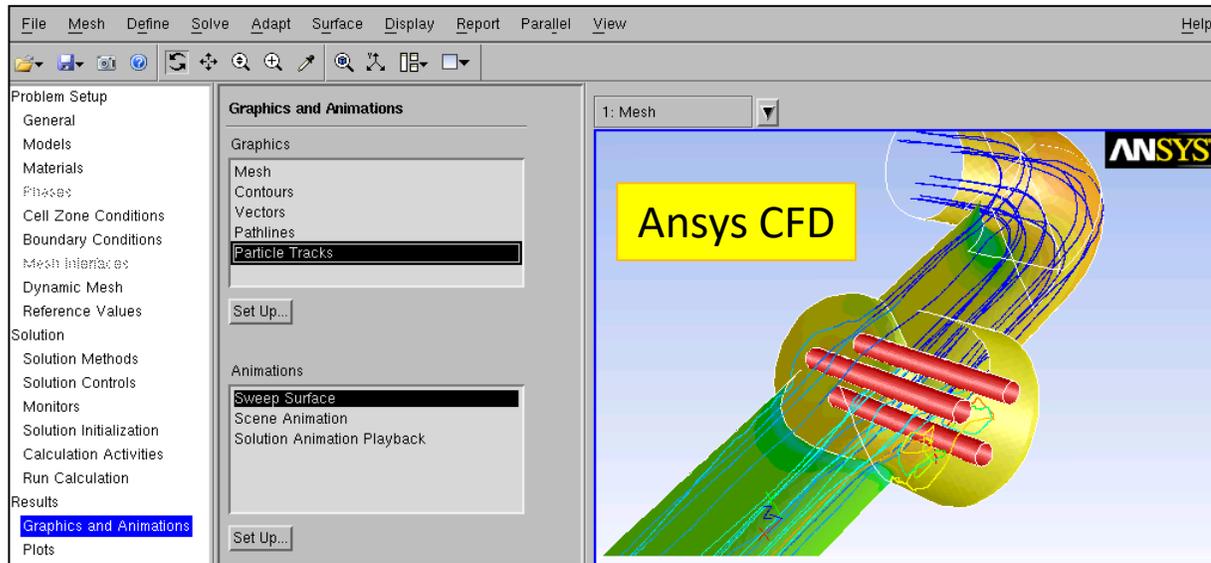
The radiometric analysis shows **minimum irradiance of 0.74 W.m<sup>-2</sup>** to achieve **minimum criteria of 20 W.s.m<sup>-2</sup>**. Desinfection process takes **27 seconds**.

# UV disinfection of cabin HVAC air

**Ansys**

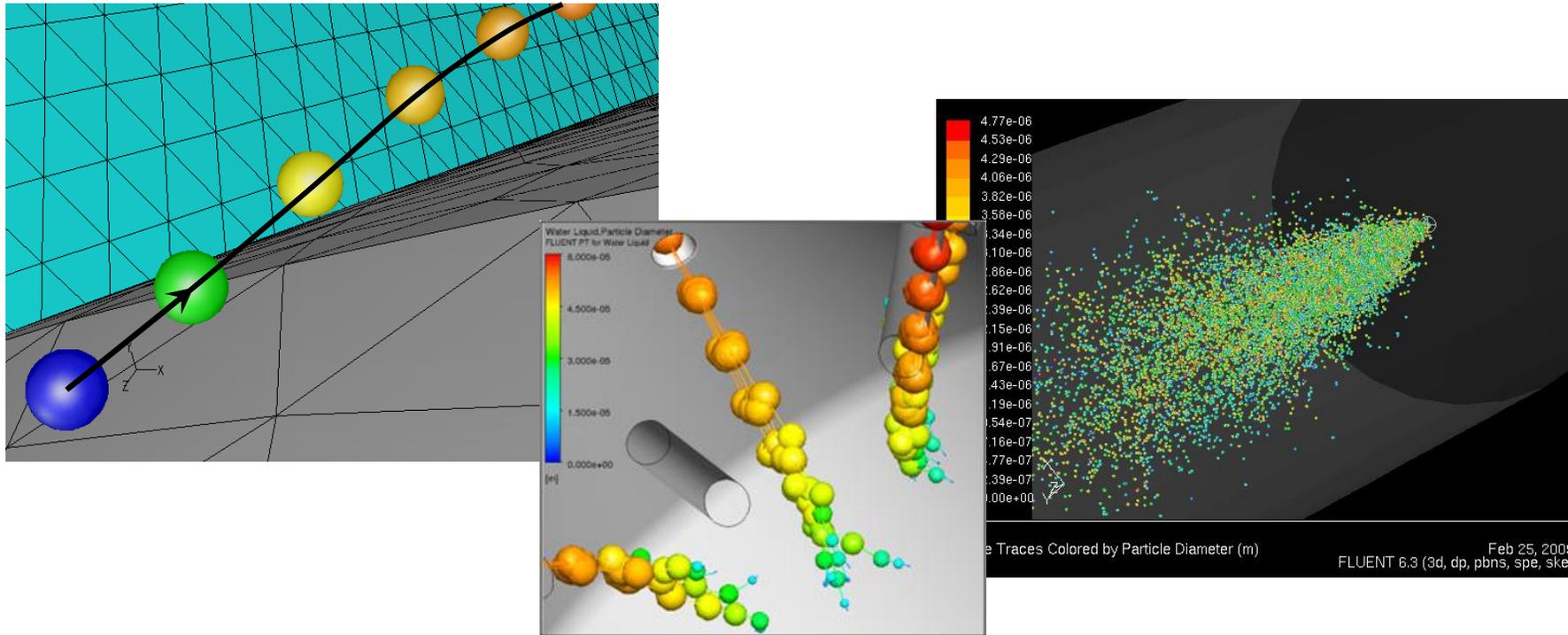
# US disinfection of HVAC air

- Model radiation with particle tracking method to simulate UV disinfection system
- Some functions are customized by UDF(User Defined Function)



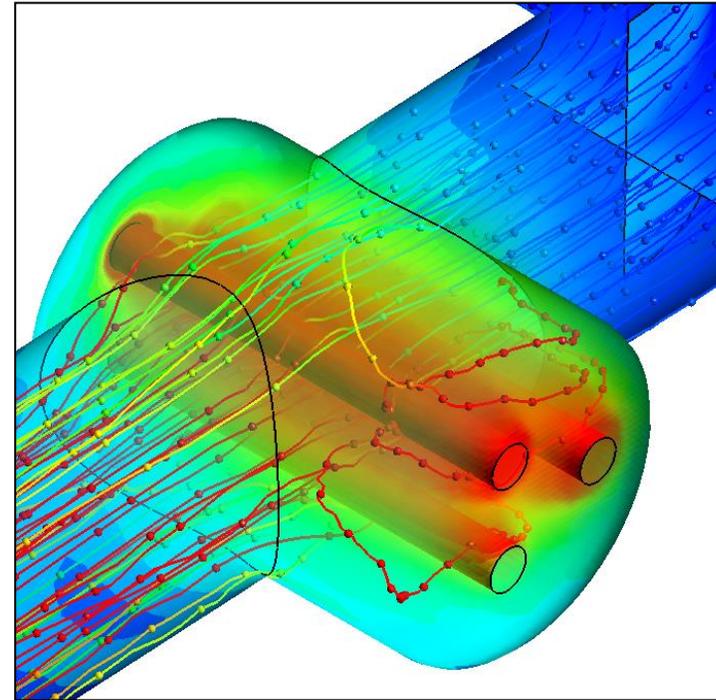
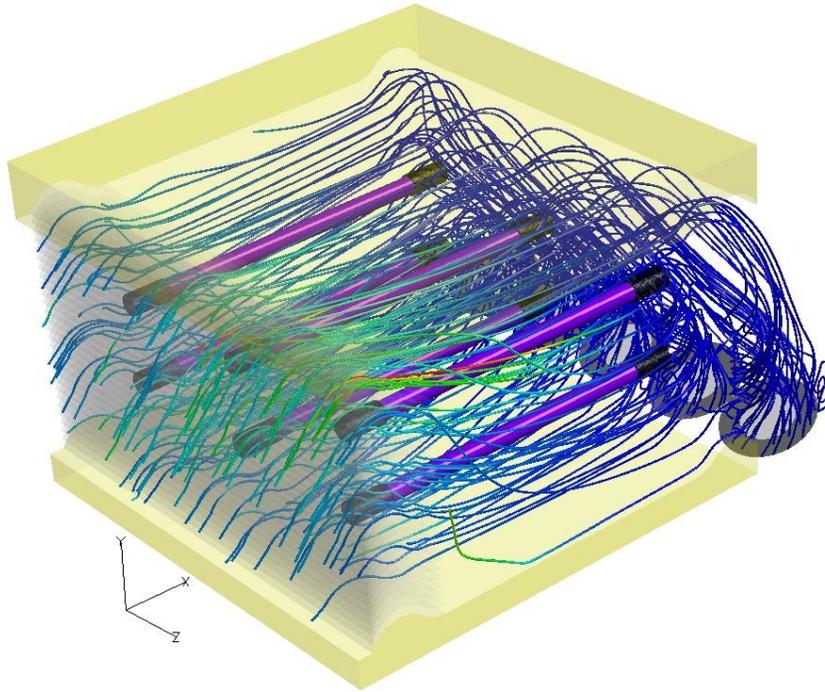
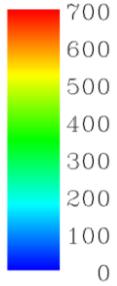
# Modeling of micro-organisms

- Micro-organisms can be modeled by Ansys Fluent DPM(Discrete Phase Model)
- Lagrangian method used to compute
  - Virus/droplet trajectories
  - UV dosage on droplets

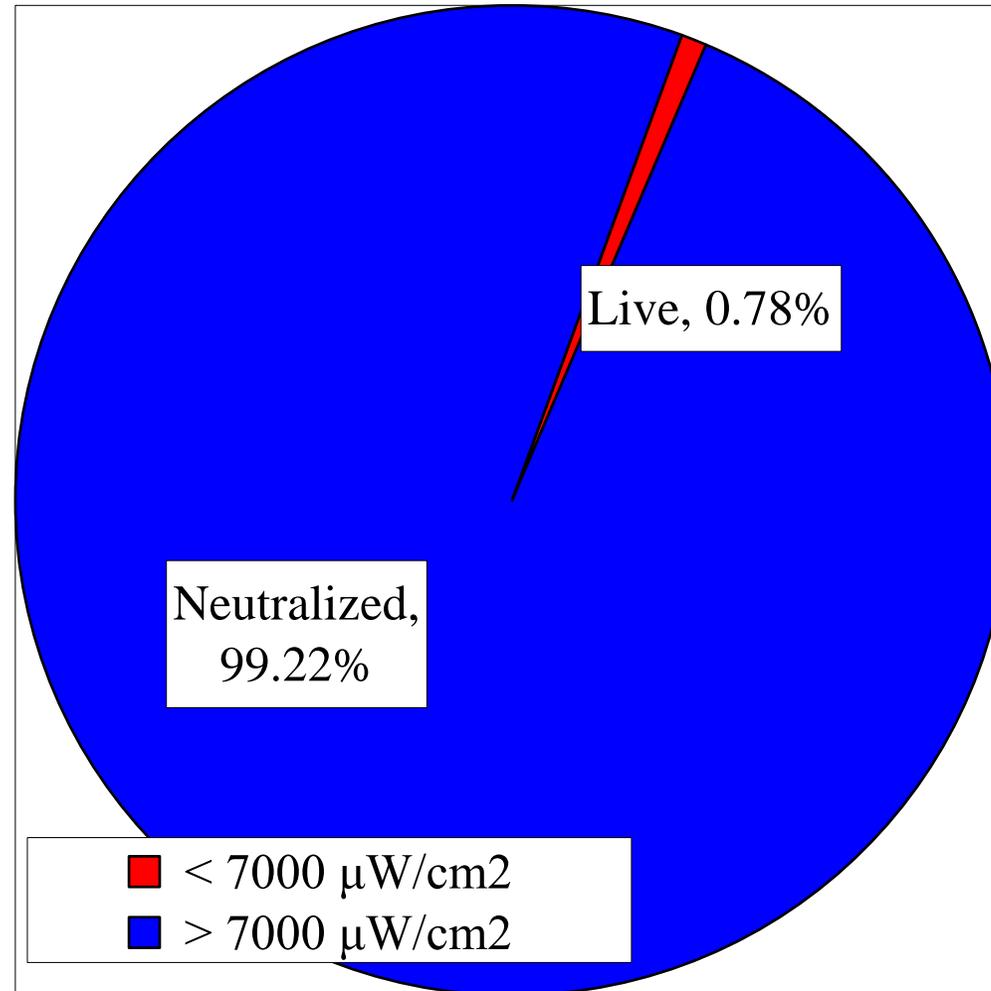
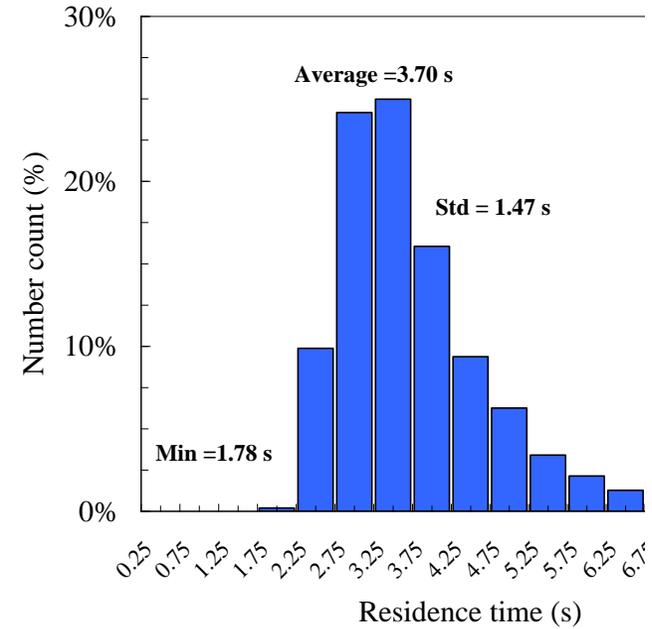


# Particle paths through ducting

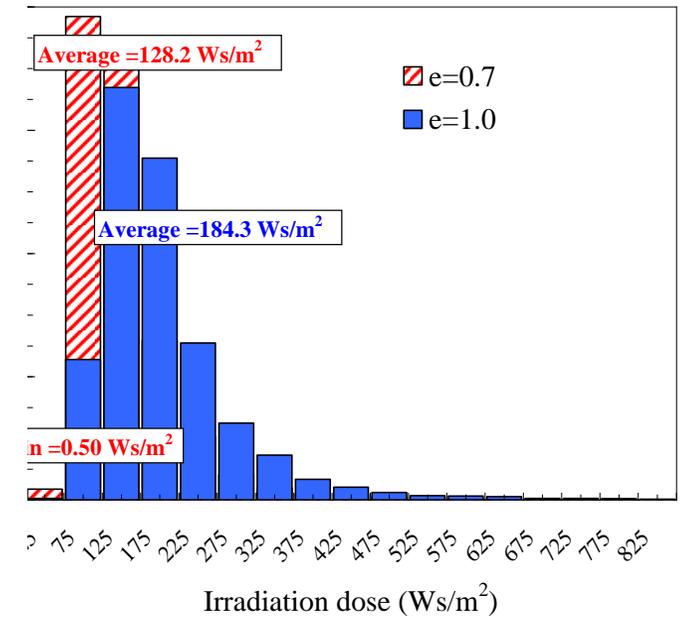
UV-C Dose  
(Ws/m<sup>2</sup>)



# Statistics of virus residence time and radiation



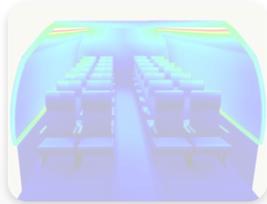
$\epsilon=1.0$



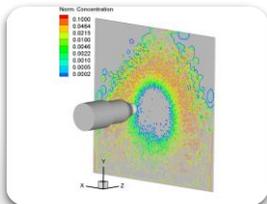
# Outline



Cabin HVAC system studies



Disinfection of cabin surfaces and HVAC air via UV light



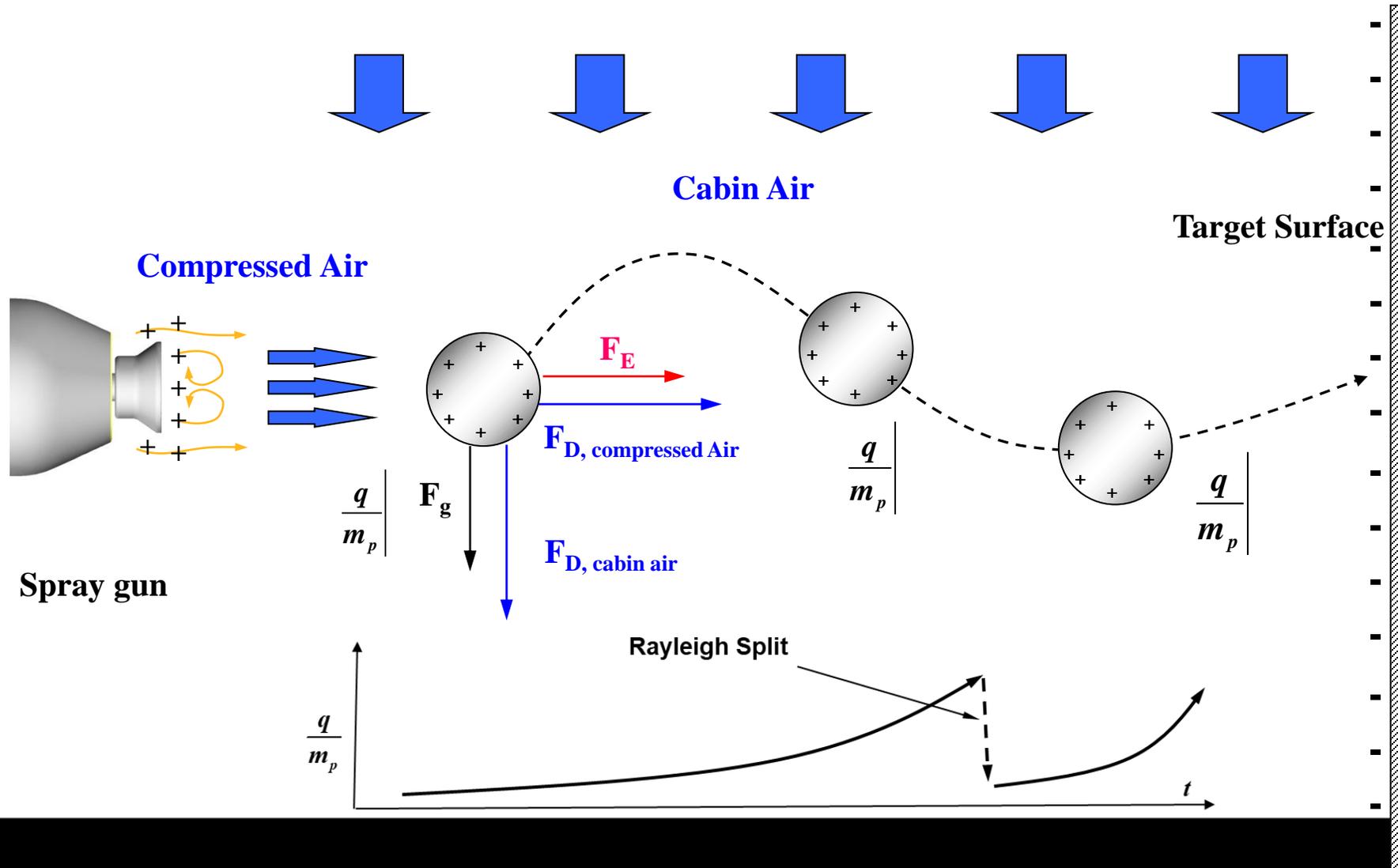
Disinfection of cabin via electrostatic sprays

# Electrostatic sprays to disinfect airliner cabins in between flights

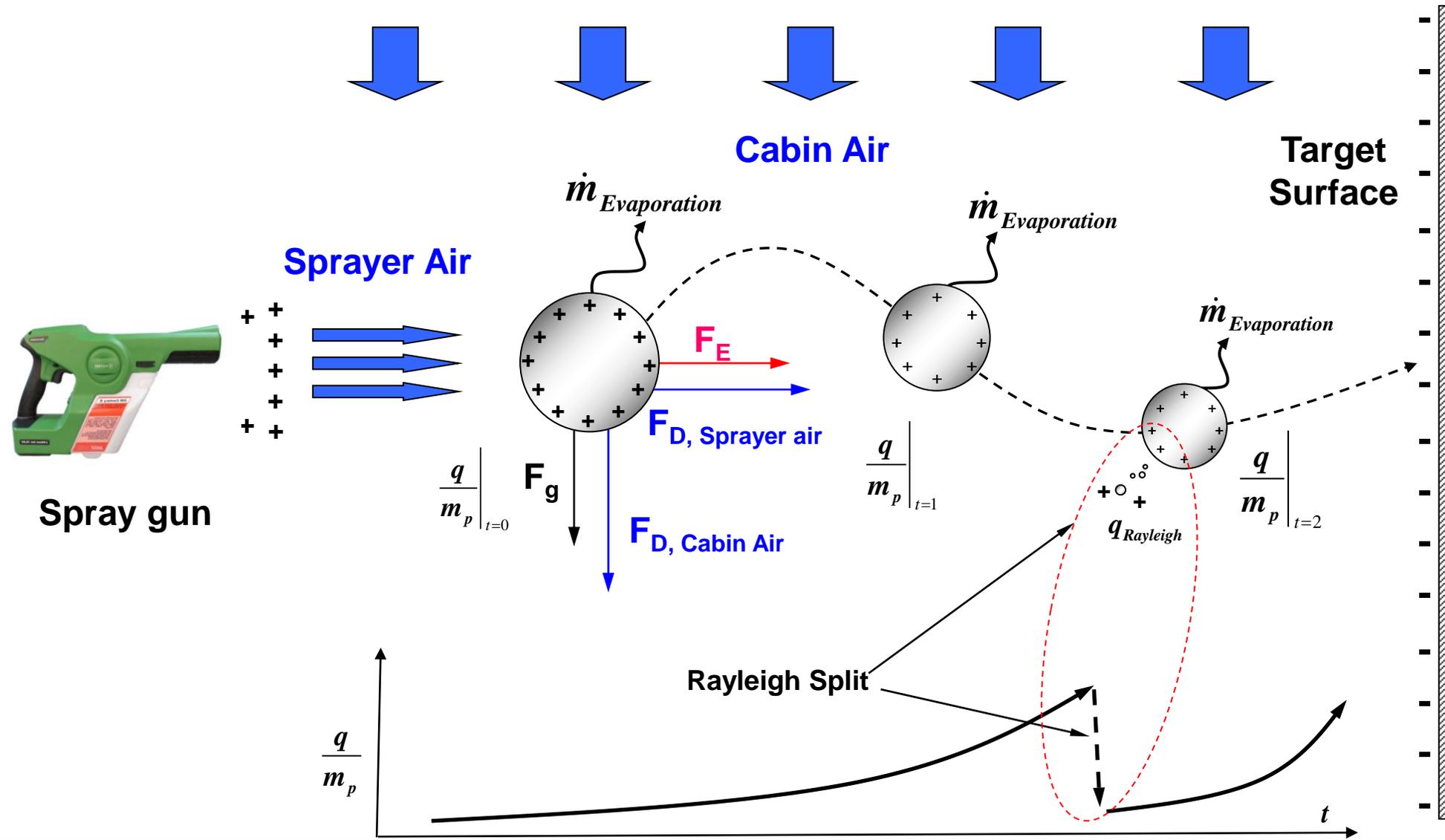


Courtesy: The Houston chronicle

# Basic Model: Forces Acting on Droplets



# Basic spray droplet physical model: forces acting on spray droplets

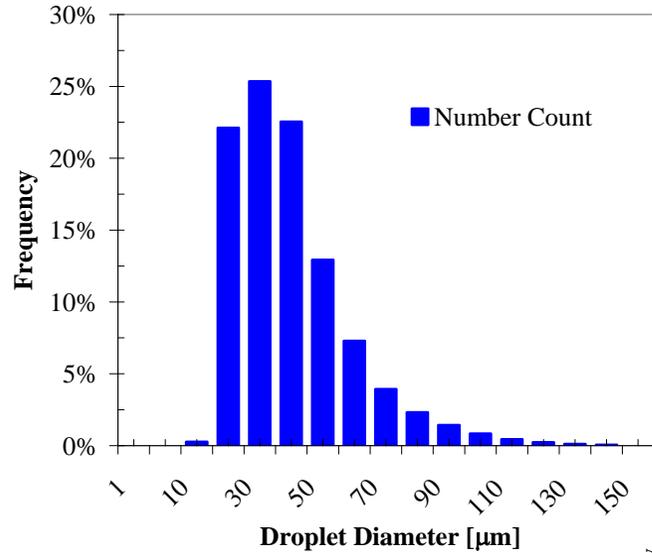


# Particle Size Distribution: experimental or computed

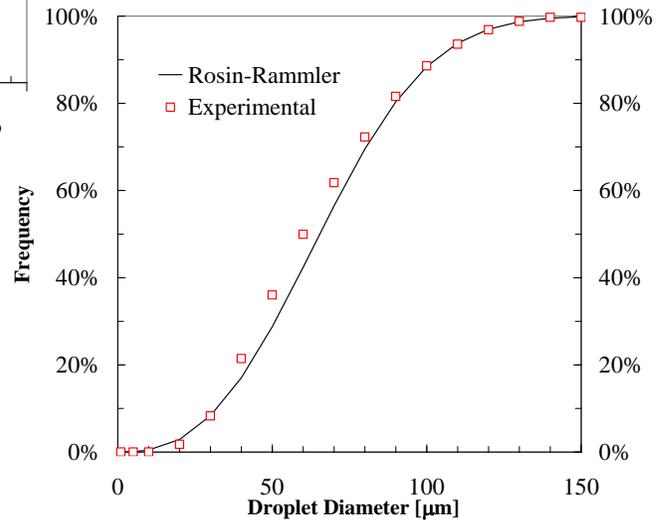
## Experimentally measured

## Computed using VOF/DPM

### Size distribution



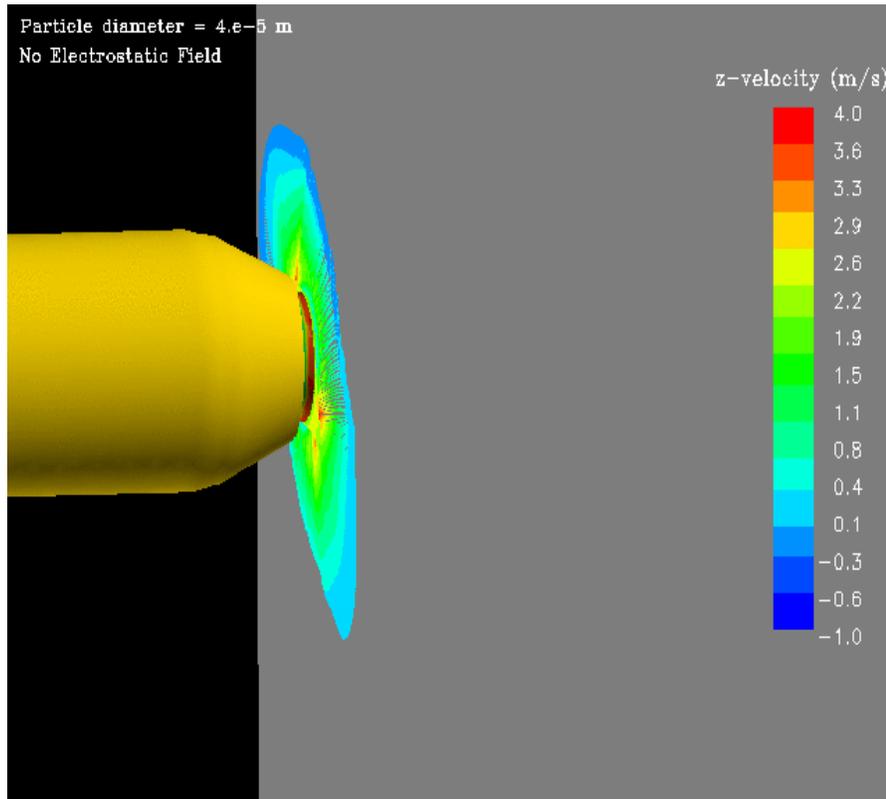
### Cumulative mass distribution



# Effect of the electrostatic field on spray droplet trajectories

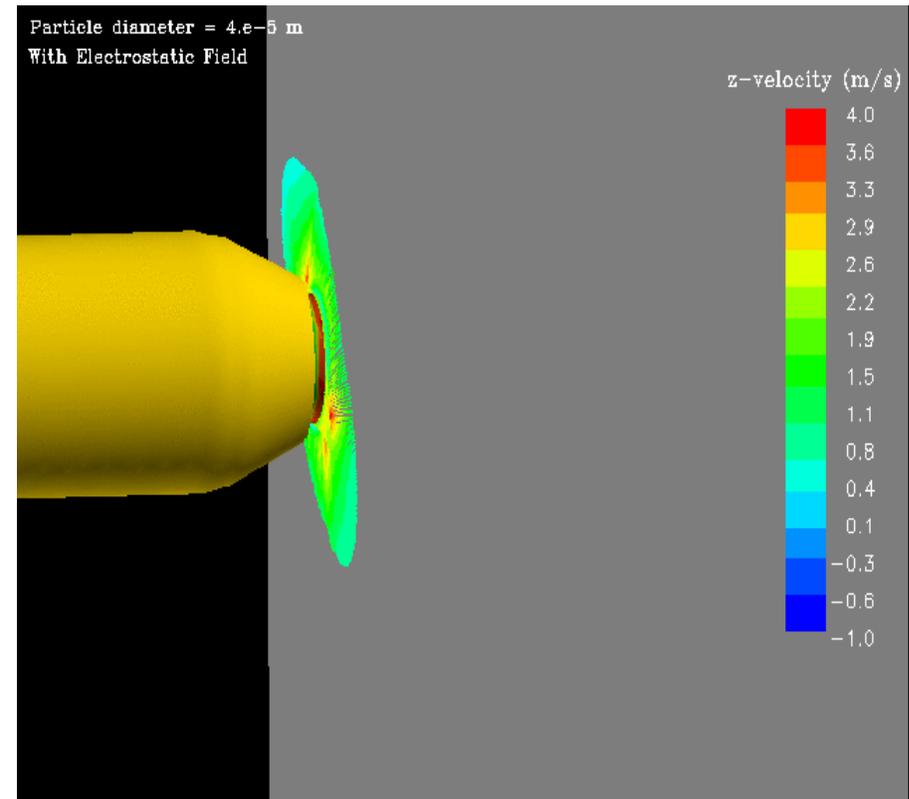
Droplet diameter = 40 $\mu$ m

Particle charge density = 0.874x10<sup>-3</sup> C/kg



No Electrostatic Field

$\eta_{\text{Transfer}} \sim 20\%$

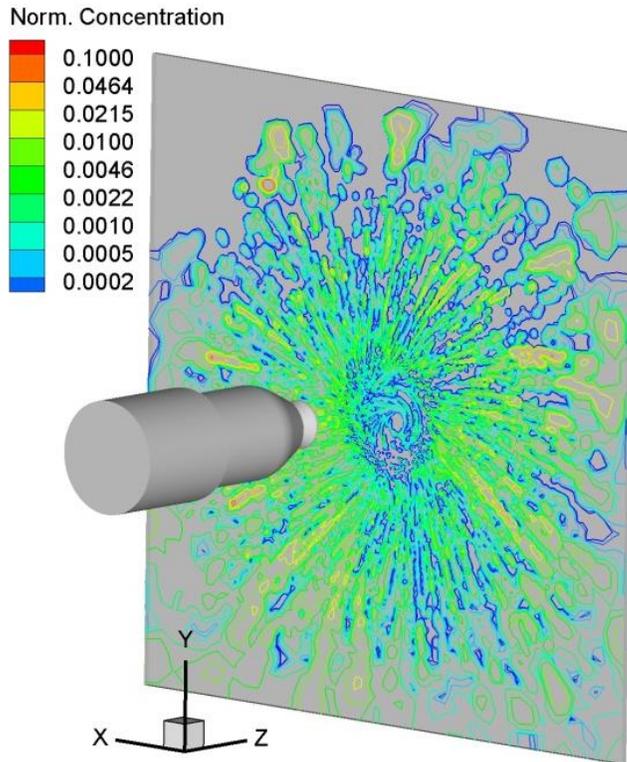


With Electrostatic Field

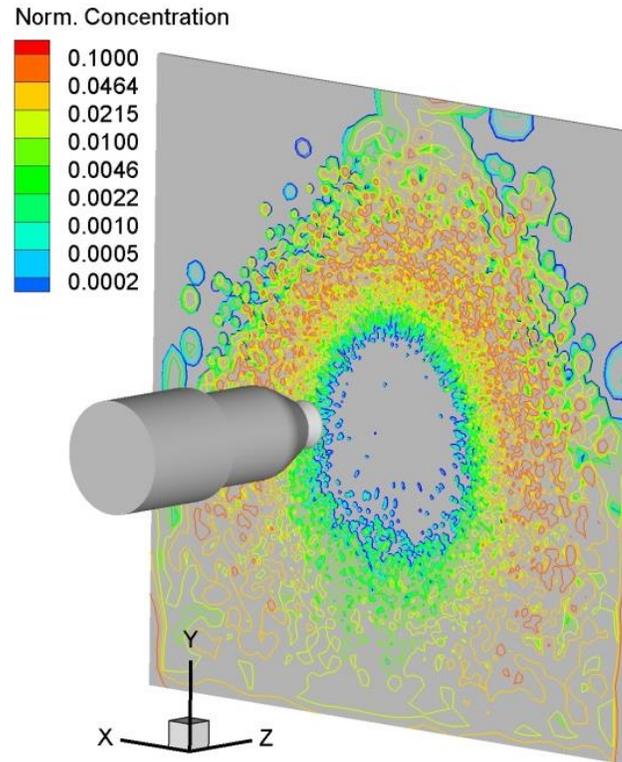
$\eta_{\text{Transfer}} \sim 78\%$

# Disinfectant film thickness on target surface

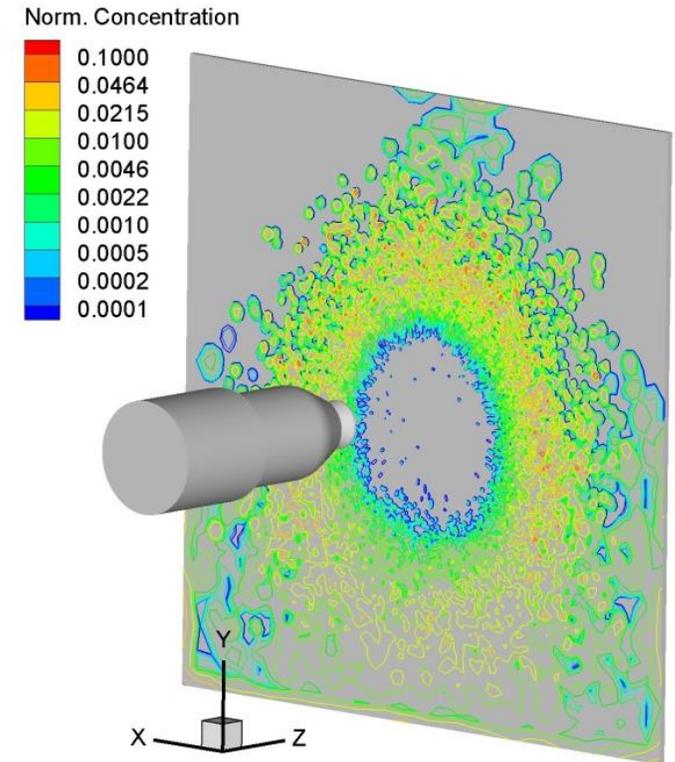
No e-field



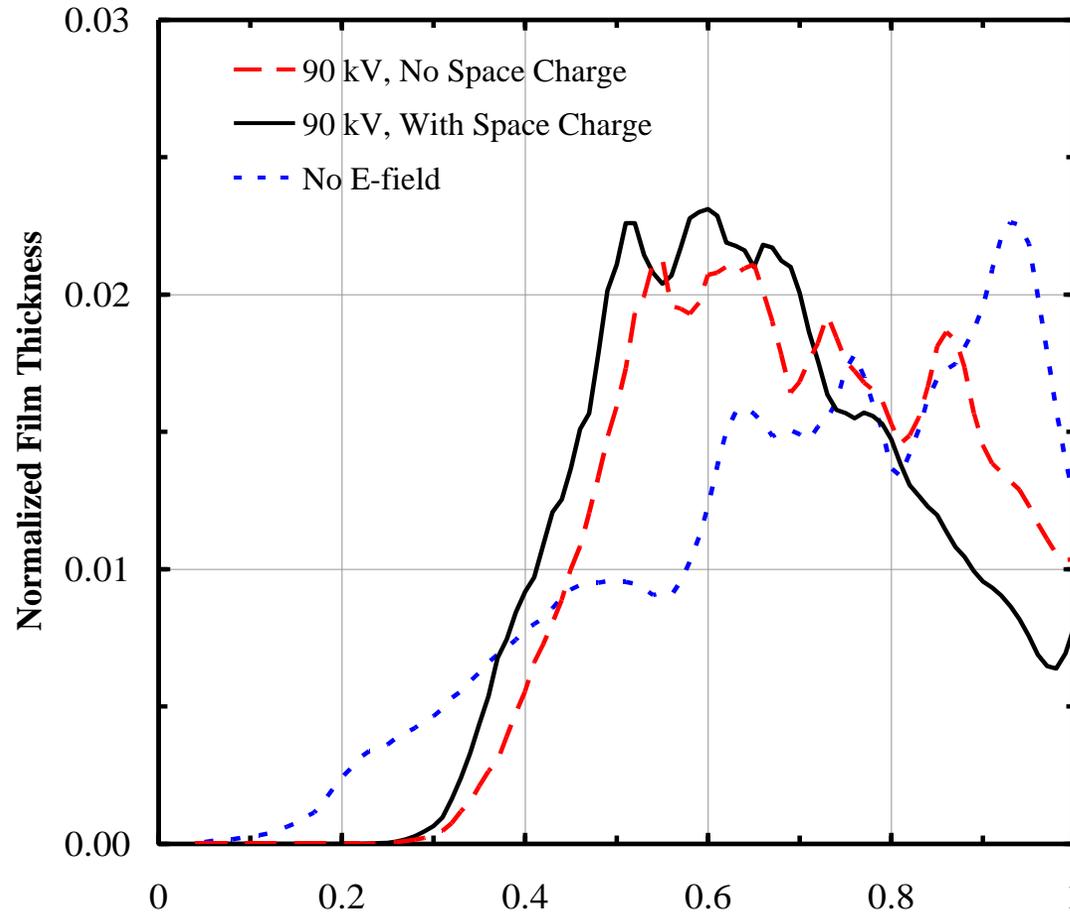
90 kV, no space charge



90 kV, with space



# Results: Averaged "Wet" Film Thickness on Target



# Thank you

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