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Pandemic-Proofing Society

POWERING AIRFLOW AND DROPLETS SPREAD STUDY WITH SUPERCOMPUTER

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11/2020

Co-innovation through Deep Multidisciplinary Modelling, Simulation and Knowledge-driven AI

Systems Science

- Complex Systems
- Multi-scale Optimisation

Social & Cognitive Computing

- Social & Behavioural Insights
- Behaviour & Cognitive Influence
- Social & Human-Level AI

Engineering Mechanics

- Design & Optimisation of Structural Materials
- Virtualisation of Manufacturing & Processes
- Design & Analysis of Engineering Systems, Reliability & SHM
- Mechanics- Coupled Systems

Materials Science & Chemistry

- Alloys & Materials Design
- Chemistry & Catalysts
- Polymers & Formulations
- Electronics & Semiconductors

Fluid Dynamics

- Coupled & Complex Flow
- Engineering Fluids Flow
- Computation for Optimisation & Design of Engineering Systems
- Physics-based Data Driven Modelling

Electronics & Photonics

- Nano & Quantum Photonics/AI
- Electromagnetics
- 3D Inverse Imaging & Optical Modelling

Computing & Intelligence

- Computational Artificial Intelligence
- High Performance Computing
- Decentralised Computing

Knowledge-driven AI

Cross-departmental Initiatives

- Digital Manufacturing Processes & Design
- Accelerated Materials & Chemicals Development
- Green Technologies for Marine, Offshore, Oil & Gas Engineering
- Environmental & Food Sustainability
- MedTech & HealthTech

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Background

Respiratory infections happened through the transmission of virus laden droplets (>5 to 10 μm) and aerosols (≤5 μm) breathed out from infected individuals during sneezing, coughing, talking and breathing.

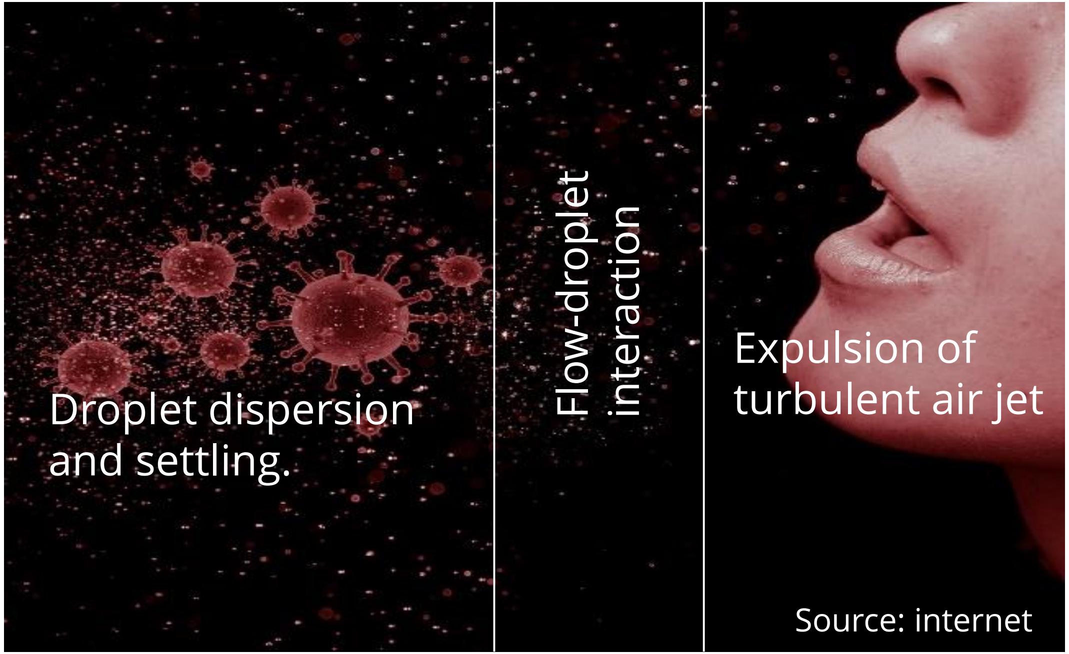
To better understand the droplet transmission, researchers at A*STAR's Institute of High Performance Computing built upon existing fluid dynamic capabilities and developed an **airflow and droplet dispersion model** from a respiratory event, in this case, a cough.

Utilising this modelling and simulation capability, the risk of the transmission and infection can be better understood.

#1: FUNDAMENTAL

- Modelling Details & Steps

Modelling Coughing Process



Source: internet

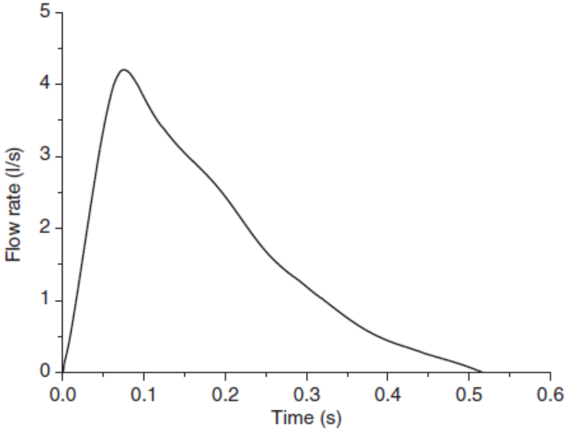
Other vocalising activities: Talking and Singing

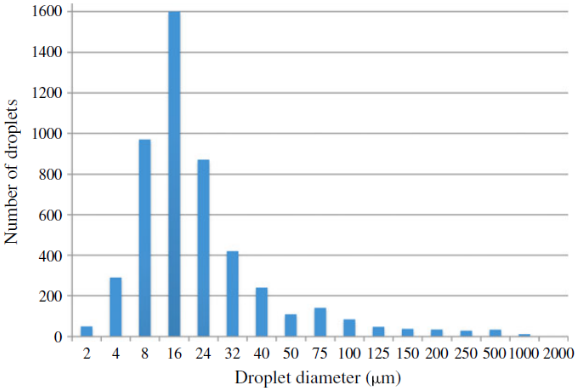
Modelling Coughing Process

Key factors taken into consideration:

1. Time dependent air flow rate (expulsion force and fluid volume)
2. Droplet size distribution
3. Cough angle
4. Mouth opening area (expulsion force)
5. Normal breathing
6. Evaporation (heat transfer)
7. Non-volatile particle
8. Only physical science is considered (biological effect i.e., viral load in the droplet is taken into consideration during analysis)

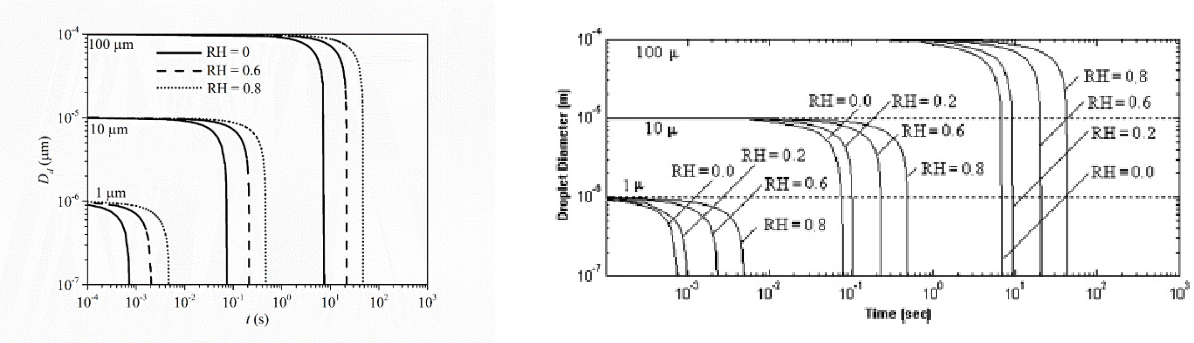
Lin Y., Li X., Yan Y. and Tu J., 2018, The Journal of Computational Multiphase Flows, 10(2), 72-82.
Gupta J., Lin C.-H and Chen Q., 2009, Indoor Air, 19, 517-525



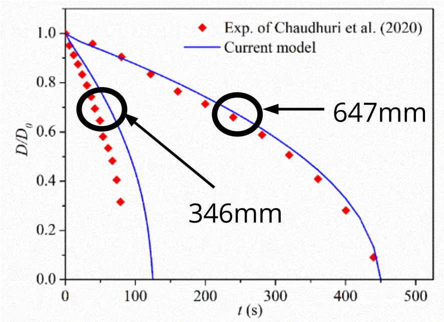


Evaporation

(a)



(b)



(a) (Left) Evaporation times for droplets of sizes 1, 10 and 100 µm under relative humidity levels 0, 0.6 and 0.8. A 10 um droplet evaporates completely in 0.2 s (RH=0.6). (Right) Graph extracted from Redrow et al.

(b) Comparison of droplet evaporation between simulation and experimental data of Chaudhuri et al. (2020)

Holterman, H. J., 2003, Kinetics and evaporation of water drops in air (Vol. 2012), Wageninger: IMAG.
Xie et. al., 2007, Indoor Air. 17, 211-225.
Chaudhuri et al., 2020. Modeling the role of respiratory droplets in Covid-19 type pandemics, Physics of Fluids. 063309-1-063309-12.

Non-volatile Particle

Component	Concentration (mg/ml)	Density (kg/m³)
Water	945	1000
Protein	23.25	2160
Lipid	19.5	1300
Carbondydrate	13.5	1100
DNA	0.834	1600
Salt	9.0	1650

Component treatment:

- Water --- 93.5% --- evaporate
- Other component --- 6.5% --- residual

Assumptions:

- The non-volatile components are treated as one volatile material with the average properties taken from the components.
- Mucus impinged on the walls including face shield are treated as trapped due to the high polymer.

Spicer S.S. and Martinez J.R., Environmental Health Perspectives, 1984, pp. 193-204
Redrow J. et al., Building and Environment, 2011, 2042-2051
Bergeron V. et al., Letters to Nature, 2000, 772-775

#2:

UNDERSTANDING SCIENCE

- Importance of Underlying Physics

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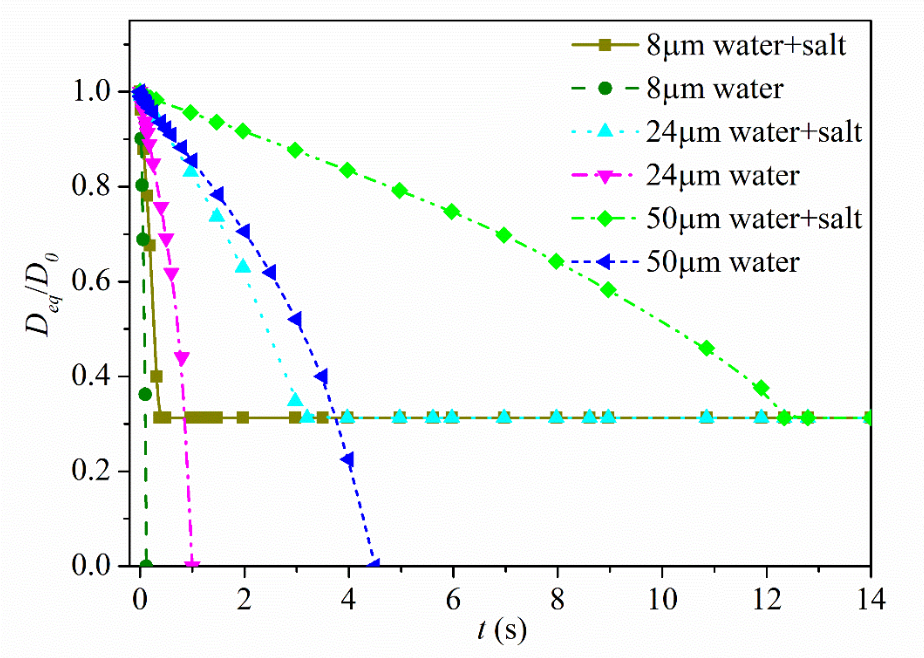
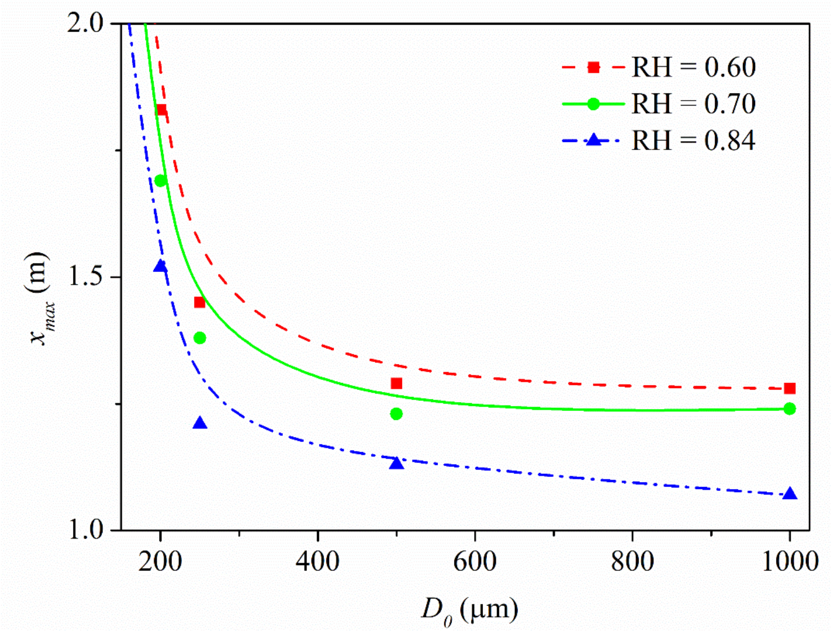
Non-volatile on Droplet Evaporation



Wind speed is 2 m/s. Ambient air temperature is 30 °C with RH = 0.84. Droplet initial temperature is 36 °C

- Evaporation time for smaller droplets is less affected by non-volatile content.
- For 50μm, evaporation time for a salty droplet is almost 3 times greater than that of pure water droplet.

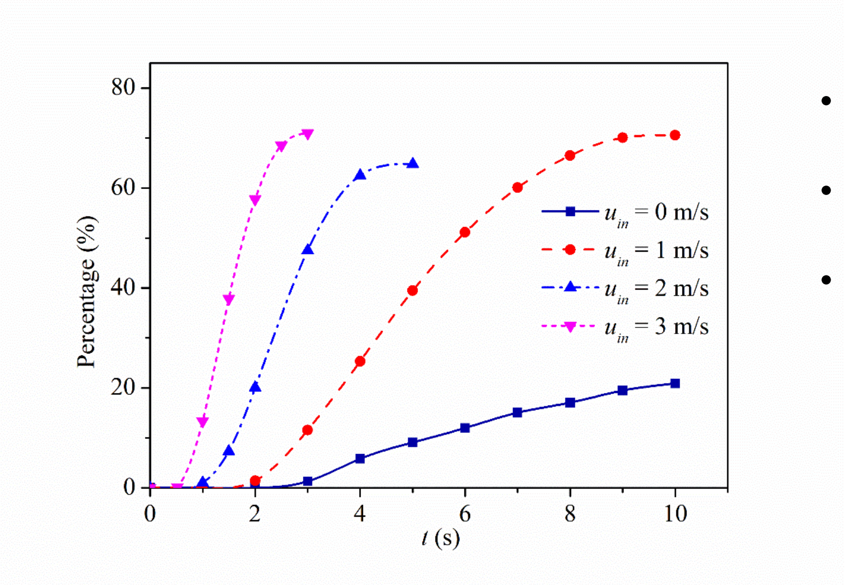
Relative Humidity and Size on Droplet Dispersion



Wind speed is 2 m/s, ambient air temperature is 30°C and droplet initial temperature is 36°C.

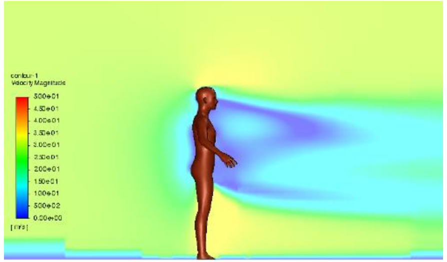
- Large droplets evaporate slower.
- Gravitational forces are predominant for large droplets.
- Travel distance at lower RH is greater than at higher RH.
- At low RH, a droplet has a high evaporation rate and shrinks, leading to longer life expectancy and travel distance.

Wind Speed on Droplet Dispersion



Wind speed is 2 m/s, ambient air temperature is 30°C and droplet initial temperature is 36°C.

- Fraction of droplets with horizontal distances exceeding 1 m distance from source at 10 s.
- 20% of the total droplet expelled by Cougher, exceeds 1m at stationary flow in 10s.
- Fraction of droplets exceeding 1 m is smaller at u_{in} = 2 m/s than either u_{in} = 1 m/s or 3 m/s.



Velocity distribution around a cougher

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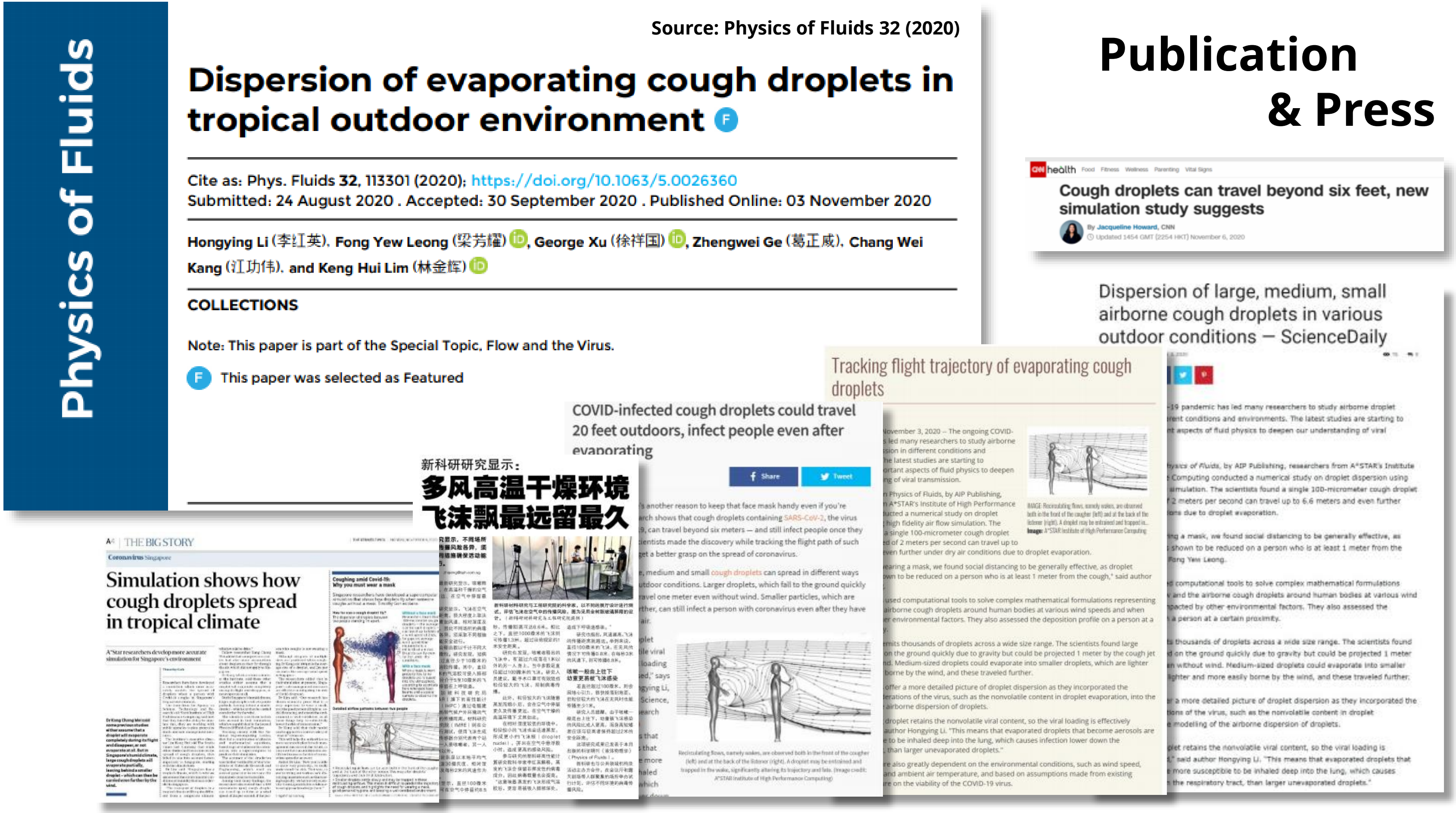
Publication & Press



Source: Physics of Fluids 32 (2020)

Physics of Fluids

Dispersion of evaporating cough droplets in tropical outdoor environment

Cite as: Phys. Fluids **32**, 113301 (2020); https://doi.org/10.1063/5.0026360
Submitted: 24 August 2020 . Accepted: 30 September 2020 . Published Online: 03 November 2020

Hongying Li (李红英), Fong Yew Leong (梁芳耀), George Xu (徐祥国), Zhengwei Ge (葛正威), Chang Wei Kang (江功伟), and Keng Hui Lim (林金辉)

COLLECTIONS

Note: This paper is part of the Special Topic, Flow and the Virus.

F This paper was selected as Featured

CNN health Food Fitness Wellness Parenting Vital Signs

Cough droplets can travel beyond six feet, new simulation study suggests

By Jacqueline Howard, CNN
Updated 1454 GMT (2254 HKT) November 6, 2020

Dispersion of large, medium, small airborne cough droplets in various outdoor conditions — ScienceDaily

-19 pandemic has led many researchers to study airborne droplet
rent conditions and environments. The latest studies are starting to
nt aspects of fluid physics to deepen our understanding of viral

hysics of *Fluids*, by AIP Publishing, researchers from A*STAR's Institute
Computing conducted a numerical study on droplet dispersion using
simulation. The scientists found a single 100-micrometer cough droplet
2 meters per second can travel up to 6.6 meters and even further
ons due to droplet evaporation.

ing a mask, we found social distancing to be generally effective, as
shown to be reduced on a person who is at least 1 meter from the
Fong Yew Leong.

d computational tools to solve complex mathematical formulations
and the airborne cough droplets around human bodies at various wind
pacted by other environmental factors. They also assessed the
a person at a certain proximity.

s thousands of droplets across a wide size range. The scientists found
d on the ground quickly due to gravity but could be projected 1 meter
n without wind. Medium-sized droplets could evaporate into smaller
lighter and more easily borne by the wind, and these traveled further.

r a more detailed picture of droplet dispersion as they incorporated the
tions of the virus, such as the nonvolatile content in droplet
e modelling of the airborne dispersion of droplets.

plet retains the nonvolatile viral content, so the viral loading is
d," said author Hongying Li. "This means that evaporated droplets that
e more susceptible to be inhaled deep into the lung, which causes
the respiratory tract, than larger unevaporated droplets."

Tracking flight trajectory of evaporating cough droplets

November 3, 2020 -- The ongoing COVID-
s led many researchers to study airborne
ssion in different conditions and
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ng of viral transmission.

n Physics of Fluids, by AIP Publishing,
n A*STAR's Institute of High Performance
ducted a numerical study on droplet
high fidelity air flow simulation. The
a single 100-micrometer cough droplet
ed of 2 meters per second can travel up to
even further under dry air conditions due to droplet evaporation.

IMAGE: Recirculating flows, namely wakes, are observed both in the front of the cougher (left) and at the back of the listener (right). A droplet may be entrained and trapped in...
Image: A*STAR Institute of High Performance Computing

earing a mask, we found social distancing to be generally effective, as droplet
own to be reduced on a person who is at least 1 meter from the cough," said author

used computational tools to solve complex mathematical formulations representing
airborne cough droplets around human bodies at various wind speeds and when
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emits thousands of droplets across a wide size range. The scientists found large
on the ground quickly due to gravity but could be projected 1 meter by the cough jet
nd. Medium-sized droplets could evaporate into smaller droplets, which are lighter
borne by the wind, and these traveled further.

offer a more detailed picture of droplet dispersion as they incorporated the
lerations of the virus, such as the nonvolatile content in droplet evaporation, into the
airborne dispersion of droplets.

droplet retains the nonvolatile viral content, so the viral loading is effectively
author Hongying Li. "This means that evaporated droplets that become aerosols are
e to be inhaled deep into the lung, which causes infection lower down the
, than larger unevaporated droplets."

re also greatly dependent on the environmental conditions, such as wind speed,
and ambient air temperature, and based on assumptions made from existing
re on the viability of the COVID-19 virus.

COVID-infected cough droplets could travel 20 feet outdoors, infect people even after evaporating

Share Tweet

's another reason to keep that face mask handy even if you're
rch shows that cough droplets containing SARS-CoV-2, the virus
9, can travel beyond six meters — and still infect people once they
ientists made the discovery while tracking the flight path of such
et a better grasp on the spread of coronavirus.

e, medium and small cough droplets can spread in different ways
utdoor conditions. Larger droplets, which fall to the ground quickly
avel one meter even without wind. Smaller particles, which are
rther, can still infect a person with coronavirus even after they have
air.

Recirculating flows, namely wakes, are observed both in the front of the cougher (left) and at the back of the listener (right). A droplet may be entrained and trapped in the wake, significantly altering its trajectory and fate. (Image credit: A*STAR Institute of High Performance Computing)

新科研研究显示：

多风高温干燥环境 飞沫飘最远留最久

A4 | THE BIG STORY

Coronavirus Singapore

Simulation shows how cough droplets spread in tropical climate

A*Star researchers develop more accurate simulation for Singapore's environment

Coughing amid Covid-19: Why you must wear a mask

Detailed airflow patterns between two people

Source: News (5-9 Nov 2020)

#3:

APPLICATION TO SCENARIOS

- Evaluation of Droplet Transport for Various Venues

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Tiered Risk Analysis

Infectivity based on viral load (copies) falling on subjects # ***- Using computer simulation***		**Ventilation efficacy of venue based on droplet particles (cm^{-3})** ***- Using experimentation***
< 58	**LOW**	< 5% of emitted particles (> 5m)
58-840	**MEDIUM**	5% - 40% of emitted particles (2m – 5m)
> 840	**HIGH**	>40% of emitted particles (< 2m)

In consultation with NCID

Based on virus copies falling on test subject's **head and hands** only

*Kelvin Kai-Wang To *et. al.* 2020, Clinical Infectious Diseases: Brief Report: https://doi.org/10.1093/cid/ciaa149
*Fengting Yu *et. al.* 2020, Clinical Infectious Diseases.
*Chia Po Ying *et. al.* 2020, Nature Communications.
+Po *et al.*, 2020, Nature Communication: https://doi.org/10.1038/s41467-020-16670-2

Case Study

Indoor Theatre
(Risk from Coughing Audience)

Start State: ***Experiment revolves around someone who coughs. No one wears mask.***

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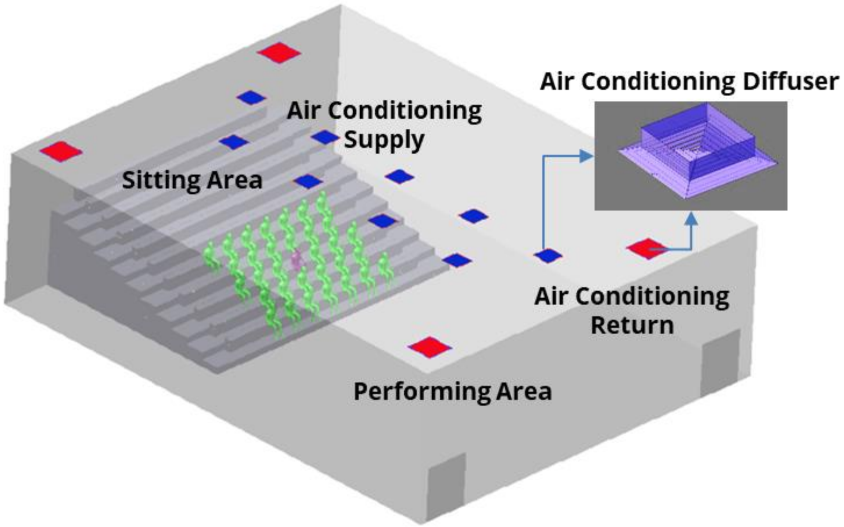
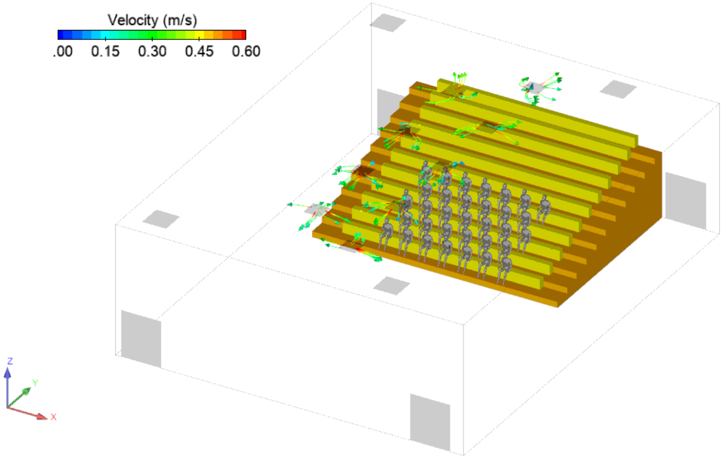
Indoor Theatre

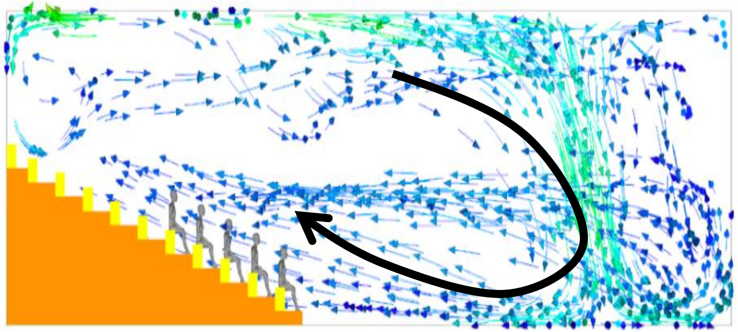
- Geometry & Air Path Lines



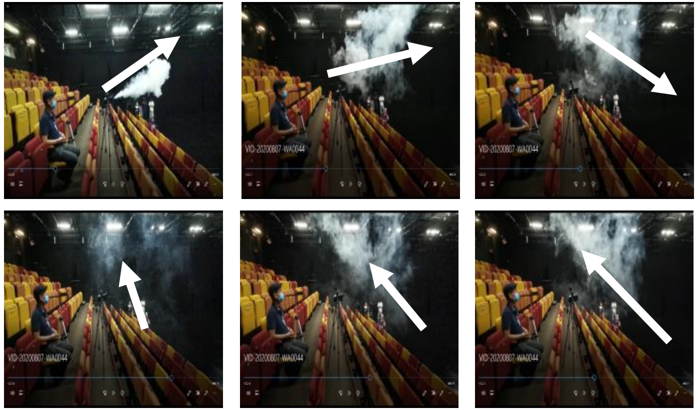


Indoor Theatre

- Validation & Further Application

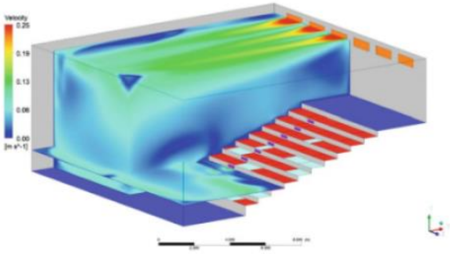


Arrow denotes how airflow rises as it pushes to the back/top of the indoor theatre: there is a lifting effect on droplets

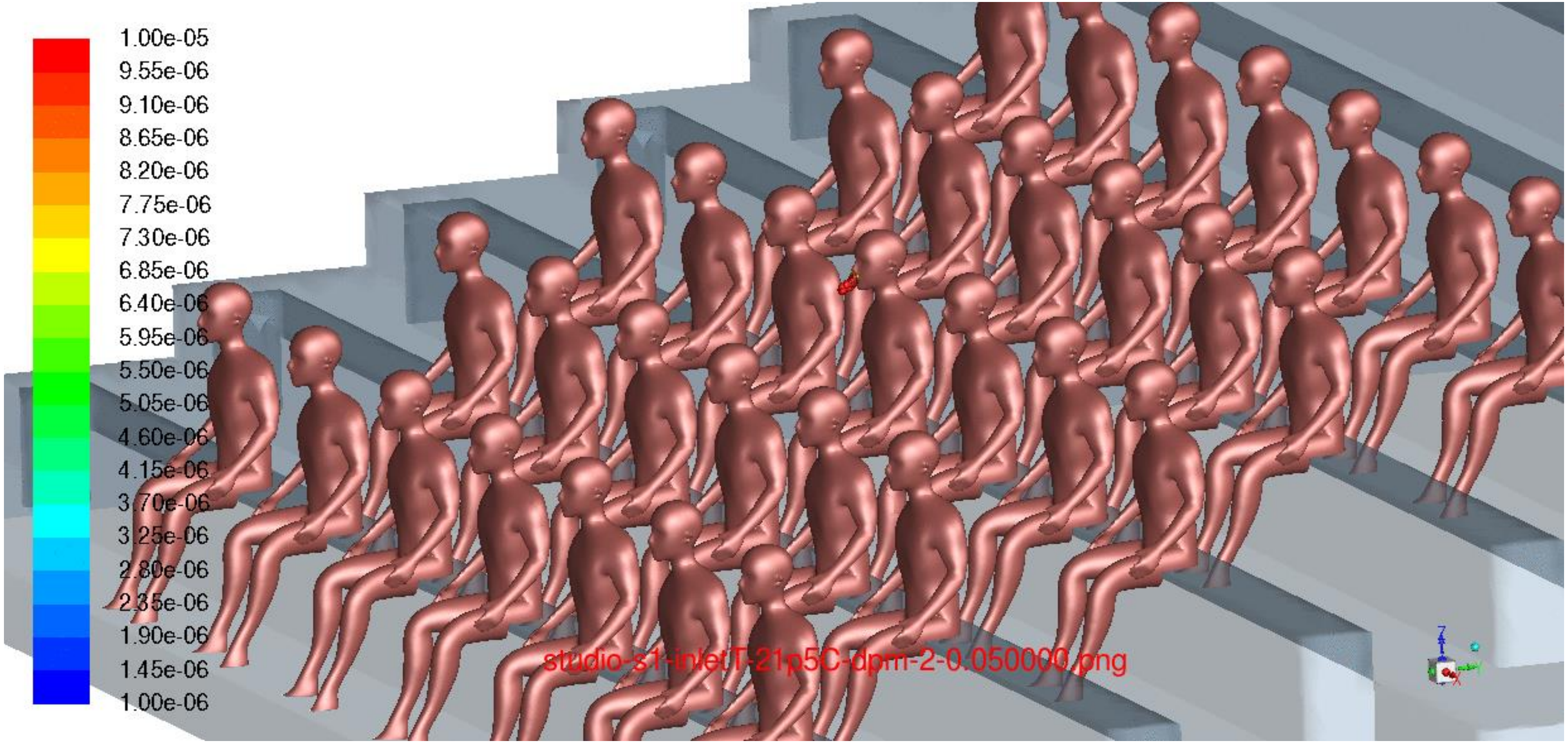


Experiment airflow video pattern is similar to simulated pattern

Similar to air flow ***within cinema***
[Rodrigues et. al. 2019, ICCSA 2019, pp.40-51]



Droplet Flow Path



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Strengths and Limitations of Study

- Strength of methodology is in coupling experimentation with computer simulation, which enables cross validation of findings.
- Study is analysed for 1 coughing action only directed to the front. Human subject is assumed to be static.
- Still numerous unknowns with regards to droplets transmission, e.g. viability of virus in droplets under various environmental conditions and duration, viral load needed for infection, etc.
- Aside from droplets transmission, there are other routes of infection, e.g. fomite, or infection that occurred outside of scenarios being studied.
- Droplets (being light) are easily affected by changes in the environmental air flow (speed and direction), site layout and location of fans / aircon / windows / etc, hence results will change when environmental conditions change
    - This study can only do experiment and simulation on a representative scenario, and generalise the broad findings.
    - Hence, risk-based analysis is used; NB: low risk doesn't mean no risk.

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Dr. CHEE Jingyee ● Dr. DAN Daniel ● Dr. Davy CHEONG
Dr. Ivan TAN

Multi-agency Collaboration

SG NSCC SINGAPORE
National Centre for Infectious Diseases
MCCY Ministry of Culture, Community and Youth
Singapore TOURISM BOARD
NATIONAL ARTS COUNCIL SINGAPORE
Building and Construction Authority
Land Transport Authority We Keep Your World Moving

For more info or collaboration opportunity, please contact:

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