Modelling Workshop Problem South Africa 2021: Covid-19 Protection Methods: masks, social distancing

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The Problem

The aim here is to gain a understand the physical processes involved in the use of masks and in social distancing; we want to know how best to use these tools to reduce the spread of this disease.

We have only 2 days and limited interaction so we will simply aim to (a) produce a report on the present state of knowledge of the processes and (b) set up simple models.

Masks

The aim is to design the best mask consistent with personal comfort. Evidently an impermeable mask exactly fitting onto the individual's face will prevent the spread but will kill the wearer. Also a comfortable but very crude and poorly fitting mask will be useless. So the question is:

What permeability (fabric thickness and weave) and fitting parameters (size, shape) will be 'best' for the wearer and for a potential victim.

Some Observations:

- The droplets (containing the virus) are carried in the air stream and will either be absorbed in the mask fabric or expelled through or around the mask.
- The volume of space between the mask and face must be sufficient and/or the mask flexible enough to allow for comfortable air exchange due to breathing.

Droplet Dispersal

One would expect sneezing to be main transmission method but normal breathing may also be important because of the longer time span involved. (We will not consider contact transmission.)

A sneeze is essentially an air jet (carrying droplets) that spreads out due to entrainment(?). The concentration of droplets in the air stream thus reduces with distance from the 'impulsive' sneeze source. How far is safe how will mask design effect this.

It would be useful to look at recent work, see a useful list below. Also we need to learn some physiology.

References

(1) Dbouk T, Drikakis D. On respiratory droplets and face masks. Physics of Fluids. 2020;32(6). doi.org/10.1063/5.0015044
(https://aip.scitation.org/doi/10.1063/5.0015044)

(2) Cummings C. P. Ajayi O. J., Mehendale F. M., Gabi R., Viola I. M. The dispersal of spherical droplets in source-sink flows and their relevance in the Covid-19 pandemic. Physics of Fluids 32, 083302 (2020).

(3) Wang B., Wu H., Wan X. Transport and fate of human droplets- A modelling approach. Physics of Fluids 32, 083307 (2020).

Modelling Issues

Remember: keep it simple!

The Mask (wearer's perspective)

The proportion of air flow through the mask depends on the gap size and resistance to air flow through the mask material.
Question 1: If δ is the average thickness of the gap around the (rectangular) mask edge (length L), and k is the permeability (so that flux/area $q = -kp_x$), determine the (leakage flux)/(mask through flux) ratio as a function of relevant parameters.

Issues:

- Should one treat the mask as being inextensible membrane (so its surface area remains fixed)?
- Should one treat the mask support (around the ears) as being inextensible or as 'springs' that adjust to inflow?
- How should mask folds and multiple fabric layers be treated?
- More generally how best to usefully describe the mechanical behaviour of the mask under inflation (experiments etc)?

- Should one 'detail' the 2-3 D flow in the thin space between the face and the mask or treat the situation as a 'leaky balloon' situation, with the balloon just just inflating or deflating due to breath. In this situation one would simply model the pressure as being uniform inside the mask and different to that outside the mask.

- How best to describe the flow situation? (impulsive, steady, periodic input from the nose/mouth)

- Evidently the mask fit will vary around the mask edges (noses etc) so the presence of a large gap at just one location could dramatically effect the flux ratio. How to model?

- Should one treat the mask through flow as 'a porous flow' (D'Arcy's Law etc) with absorption; this would take into account detailed flow variations through the thickness of the mask. Or should the mask be treated as a thin membrane with a pressure difference across it driving the throughflow?

- How should one model the absorption of droplets in the fabric of the material. Again one could either decide to detail moisture variations within the mask material or simply work with the (total) moisture content of the mask material per unit surface area (thus ignoring variations).

- Mask saturation effects? How to model?

Sneeze (no mask)

- A (classical) steady state (turbulent) jet entrainment model would assume a uniform velocity (or prescribed profile) through the stream with essentially no (longitudinal) flow outside the jet in the flow direction but with a small inflow due to to entrainment. The input mass flux and momentum flux (at the nose) would be prescribed. The sectional area of the stream will increase due to entrainment. The sneeze is evidently non steady (probably impulsive) so model development is needed (we need a literature search here).

- How to model moisture (droplet) concentration levels in the stream?

  Question 2: How does the sectional area of the jet vary with distance from the source, and what concentration levels will result?

- How to model the (time varying) impulsive flow input from the sneeze? How to model the periodic input due to normal breathing? (lung action, moisture content in the expelled air, breathing time,...)

- It may be necessary (and certainly interesting) to model spray generation (pneumatic atomization? impulsive liquid expulsion?); in any case we need to understand this process.

Suggested Group Organisation/Activity

Depending on numbers the (modelling workshop) group should be divided up into three subgroups: a reference examination group (I suggest at least 2 members looking at each of the three listed papers), a mask model group (at least 3 members) and a sneeze group (at least 3 members). Participants should opt into a group and identify/work with the members of that subgroup quickly (ie soon after lunch Thurs); there is little time. If any of the initially formed subgroups contains less than the numbers suggested above those members should join a different group. It is suggested that reference 1 and and question 1 should have highest priority.

Each of these subgroups should present progress in the evenings and report to the total group at 8.30 am each day so we can decide what needs doing.

The group as a whole should provide a final presentation containing (a) a concise summary of reference material and (b) a description of the modelling work. The presentations should be typed and 'formal'; Beamer, PowerPoint or equivalent. AIMS students are expected to produce a (more detailed) typed report as part of the MSc assessment. This report can be on any one problem arising out of the modelling workshop or the MISG and should be completed by 1 week after the MISG meeting.