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E-PiPEline: Quick to Market Face Coverings and Face Shields Using Commonly Available Materials

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1.1. Overview

The Center for Disease Control has recommended that the public should wear cloth face coverings in public settings. Face coverings and face shields can be made by using Commonly Available Materials (CAMs). As part of the Sandia COVID-19 LDRD effort (funded under the Materials Science Investment Area), the Sandia E-PiPEline task evaluated design options for face coverings and face shields considering their effectiveness, durability, build difficulty, build cost, and comfort. Observations from this investigation are presented here to provide guidelines for home construction of face coverings and face shields. This executive summary includes a brief roadmap of the analysis methodology, two one-page handouts geared to be distributed to the public at large (one for face coverings and one for face shields), and additional observations regarding potential solutions for face coverings and face shields included to further support the one-page handouts.

1.2. Methodology

Analysis methodology techniques that are transparent and defensible were used to provide an analytic framework that articulates the design options, enumerates the assumptions, and provides a semi-quantitative assessment of alternatives while providing a clear linkage between analysis steps. The methodology employed followed the following steps:

1. Understand Design Alternatives in the Literature
2. Define the Design Space Identifying Design Characteristics and Options
3. Enumerate Alternative Designs
4. Develop Evaluation Metrics and Scoring Rubrics
5. Score Alternative Designs
6. Analyze Design Space for Trends and Develop Recommendations

1.3. Face Covering Design Space

A large design space was examined for the face coverings (over 200,000 design combinations) using a systematic process. This design space using CAMs includes the following design options

Number of Layers: 1, 2, or 3

Mask Material in Each Layer: (1) Tight Non-Woven Hydrophilic Coated Polypropylene Based, (2), Non-Woven Polypropylene Based, (3) Non-Woven Polypropylene/Polyester Blend Based, (4) Lignocellulosic Based; (5) Non-Woven Cohesive Polyester/Elastomer Blend Based; (6) Woven Cotton Based <600 Thread Count Based; or (7) Tight-Woven Cotton Based >600 Thread Count Based

Layer Connection Location: Around Edge, Around Edges and Center, or None

Layer Connection Mechanism: Staple, Glue, Sew, Friction, or None

Strap Attachment Material: Same as Layer 1, Same as Layer 2, Same as Layer 3, Elastic Band, Tourniquet Band, Velcro Straps, Rubber Band, Cohesive Bandage, or Latex Gloves

Strap Attachment Mechanism: Staple, Glue, Sew, Tape, Compression, or Integrated

1.4. Face Shield Design Space

The face shield design space (900 design combinations) using a systematic process includes the following CAM design options

- **Shield Material**: Cellulose Acetate, Polypropylene & Vinyl, Polyethylene Terephthalate, Polypropylene, or Polyester
- **Structure**: Foam, Safety Glasses, Velcro Straps, Cardboard, Tongue Depressor, or Rolled Paper
- **Strap Attachment Material**: Rubber Band, Cotton Fabric, Velcro Straps, Cohesive Bandage, Elastic Band, or Latex Gloves
- **Strap Attachment Mechanism**: Staple, Glue, Sew, Tape, or Compression

2. ONE-PAGE HANDOUTS

2.1. Face Covering Designs Using Commonly Available Materials

See Page 7 for the one-page handout developed describing Observations Regarding Face Covering Designs Using Commonly Available Materials.

2.2. Face Shield Designs Using Commonly Available Materials

See Page 8 for the one-page handout developed describing Observations Regarding Face Shield Designs Using Commonly Available Materials.

Observations Regarding Face Covering Designs Using Commonly Available Materials

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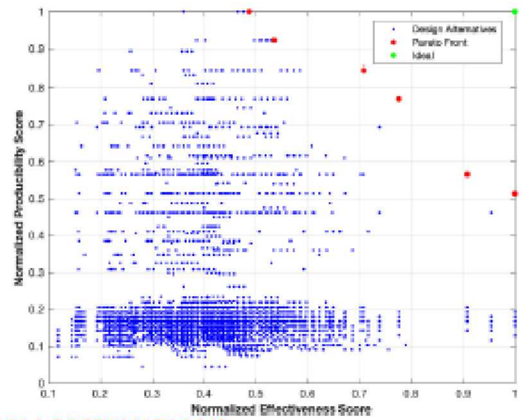
The Center for Disease Control has recommended that the public should wear cloth face coverings in public settings[1]. A Sandia COVID-19 LDRD effort, the Sandia E-PiPEline Team, systematically evaluated design options for face coverings constructed from commonly available materials (CAMs). The design options were analyzed with subject matter expert input considering the design's effectiveness (metric fiber density, material construction, and water saturation), reusability (degree of inertness), producibility (ability to obtain materials, build time), cost, and comfort (fit on face, breathability). Observations for the design of face coverings using CAMs are provided here.



DESIGN SPACE

The principle design characteristics and alternatives considered for the construction of a face covering are listed below.

- Number and materials of layers: 1-3 layers; woven cotton materials, paper-based materials, synthetic fabrics
- Connection method and location between layers: sewn, glued, stapled; around edge or center and edges
- Treatments of the top layer: machine wash, bake in oven, iron, machine dry, none
- Attachment methods: integrated designs, compression straps, Velcro straps

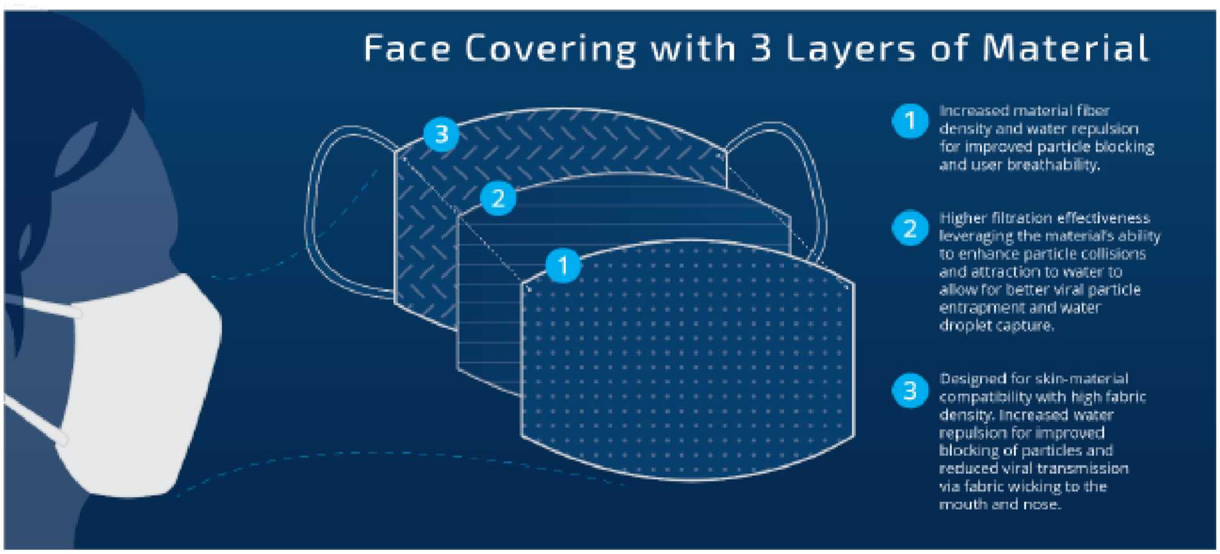
The graphic at top illustrates the results of scoring more than 200,000 designs evaluated for face coverings using CAMs. The normalized design scores are shown in blue, with the best options shown in red. The scores are normalized relative to the highest score in the effectiveness and producibility metrics.

DESIGN OBSERVATIONS

- More layers increase effectiveness
- Full coverage over mouth and nose reduces chances of particles reaching the face
- Mask conformability improves effectiveness

MATERIAL OBSERVATIONS

- Leverage cotton and paper-based materials to capture aerosolized water droplets within the fiber matrix
- The placement of natural-based materials sandwiched between two water repelling synthetic based materials decreases liquid movement towards the face
- Using materials with high fabric density to improve particle filtration while maintaining user breathability
- Prioritize user safety by selecting materials that reduce loose material particle inhalation hazards



[1] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover.html

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Observations Regarding Face Shield Designs Using Commonly Available Materials

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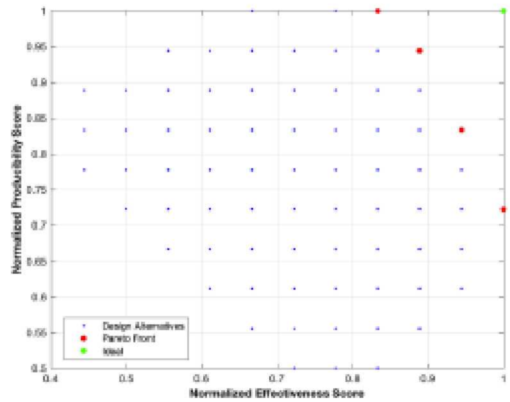
A Sandia COVID-19 LDRD effort, the Sandia E-PiPEline Team, systematically evaluated design options for face shields constructed from commonly available materials (CAMs). This study is not focused on face shields for medical applications, and as such, has excluded labeling and flammability considerations suggested by the FDA. Design options for face shields were analyzed with subject matter expert input considering the design's **effectiveness** (seal around face), **reusability** (compatibility with solvents, degree of inertness), **producibility** (ability to obtain materials, build time), **cost**, and **comfort** (fit around head, contact surface interface). Observations for the design of face shields using CAMS are provided here.



DESIGN SPACE

The principle design variables considered for the construction of a face shield were:

Primary shield material: polyethylene, polypropylene, cellulose acetate

Structural material: foams, safety glasses, cardboard, wood

Attachment methods: sewn, glued, stapled

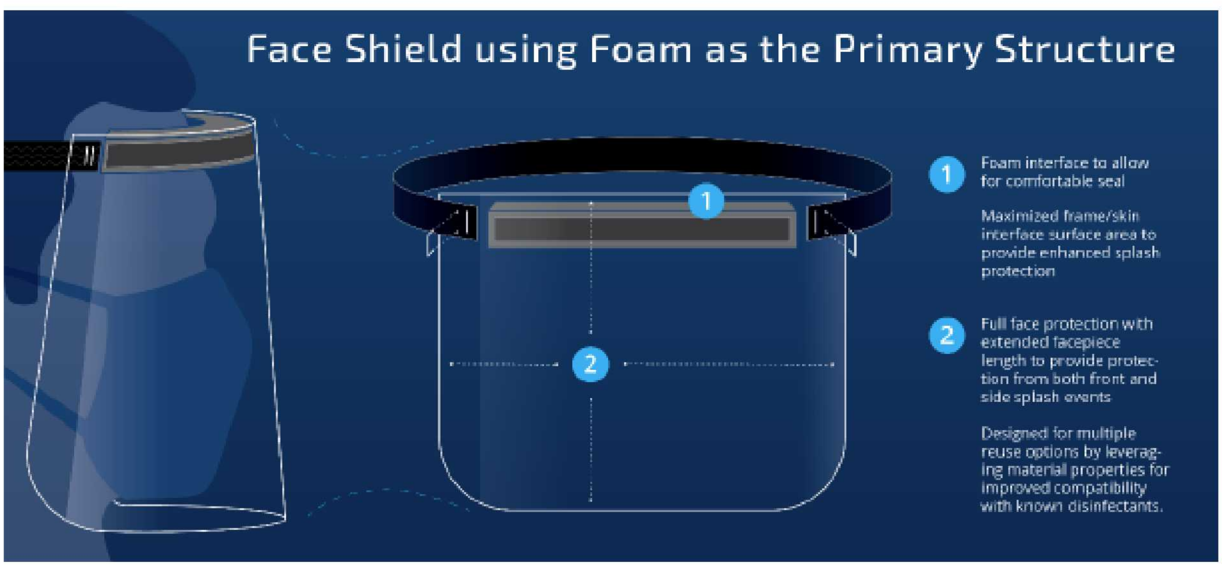
The graphic at top illustrates the results of scoring more than 900 designs evaluated for face shields using CAMs. The normalized design scores are shown in blue, with the best options shown in red. The scores are normalized relative to the highest score in the **effectiveness** and **producibility** metrics.

DESIGN OBSERVATIONS

- Minimizing the gap between the face shield and the forehead will help reduce the chance of liquid splash to the eyes
- It is important that the face shield extends down below the chin and stretch around the full-face area
- Designs that use compression to attach the face shield to the face were observed to be promising

MATERIAL OBSERVATIONS

- Using foam as the primary frame/face interface material provides splash protection
- For reuse of the face shield, choosing materials that are compatible with common solvents, like polypropylene



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3. ANALYSIS OBSERVATIONS

3.1. Face Covering Material and Design Observations

3.1.1. Observations

The following observations from the data in the E-PiPEline study were made for the face covering:

- Leverage cotton and paper-based materials to capture aerosolized water droplets within the fiber matrix.
- The placement of natural-based materials sandwiched between two water repelling synthetic based materials decreases liquid movement towards the face
- Using materials with high fabric density to improve particle filtration while maintaining user breathability
- More layers increase effectiveness
- Full coverage over mouth and nose reduces chances of particles reaching the face
- Mask conformability improves filtration effectiveness.

It was observed that the more layers the better. Assuming a three-layer face covering the following observations were made regarding the selection of materials for each layer:

For the *layer furthest from the mouth*, one should increase inertial impaction factor by maximizing fabric fiber density. This will likely increase the probability of blocking aerosolized viral particles. Selecting first layer materials that have a **low water absorption** may also reduce water saturation and increase mask durability and breathability.

The *middle layer* should be designed for material interchangeability. Using **non-woven fabrics with high fiber density** will likely increase filtration effectiveness by providing a tortuous path for particles resulting in increased particle collision and entrapment in the middle layer. Materials with increased water absorbance provide a matrix for aerosolized liquid water capture. Additionally, the middle layer should have design features that allow for material interchange after high particle loading and water saturation which can reduce filtration effectiveness and user breathability.

The *layer closest to the mouth* should be designed for mouth and nose interface compatibility and with **high water repelling properties**. Select materials with a **high fiber density**. Do not select loose materials or weaves to prevent inhalation of material borne particles. By choosing these materials the user can reduce the chance of viral transmission via water wicking to the mouth and nose.

3.1.2. Using the Observations for Practical Steps to Materials Selection for Face Coverings

The following are steps to interpret, evaluate, and use the observations provided in the design and creation of a face covering.

1. Understand the material's fiber parameters. Categorize your materials based on whether base fibers are synthetic or natural and if the fibers are small or large in diameter. Synthetic fibers are usually stronger and more durable for longer use situations as well as usually maintain a low water absorption while small fibers usually indicate a high fiber density.

2. Determine if the material stretches when pulled indicating a knitted or loose weave structure or if conversely the fabric is very stable under tension indicating an increase in fiber density with a non-woven or tight weave structure. Choose materials with a high fiber density that will maintain their shape when put under tension.
3. Determine if the fabric has any coatings, ink, or other surface treatment. A quick way of determining this is simply testing the fabric under water and check if water is repelled or absorbed by the material. Additionally, check if the treatment is applied to one or both sides of the material with the understanding that the water-absorbing material faces should point away from the mouth or nose and placed further away from the mouth. This will minimize water wicking towards the mouth and nose interface of the mask.

3.1.3. Material Observations

Table 3-1 provides an assortment of the materials examined in this study for the face coverings, observations regarding these materials, and observations regarding the location in the design of a face covering.

Table 3-1. Practical Description of Materials, Observations, and Locations

Material Types	Examples	Water Saturation Potential	Face Coverings Observations	Highest Scored Face Covering Layer
Cotton with High Fiber Density	Pillowcases, flannel, high tread count clothing	Medium	Easy to wash, absorbent, fairly durable, high fabric density.	Layer closest and furthest from the mouth
Cotton with Medium to Low Fiber Density	Shirts, bandanas, woven gauze, scarfs	Medium	Easy to wash, absorbent, fairly durable, low fabric density	Middle Layer
Polypropylene	Professional/shop towels, Haylard surgical wraps, medical grade fabrics.	Very Low	Low water absorption, high fabric density, very durable	Layer closest and furthest from the mouth
Polyester Blends	Surgical masks, general shop towels, non-woven gauze, sports and performance apparel	Low	Low water absorption, high fabric density, dries quickly, durable	Layer closest and furthest from the mouth
Paper Based	Coffee filters, paper towels, stretcher tissue paper	High	High water absorption, varying degree of fabric density	Middle Layer

3.2. Face Shield Material and Design Observations

The following observations were made from the analysis of the data regarding materials for the face shield.

- The most highly scored options used a foam as the primary frame/face interface material to provide the most effective liquid splash protection
- For reuse of the face shield, choosing materials that are compatible with solvents like polypropylene is crucial.

The following observations were made from the data regarding the design for the face shield.

- Minimizing the gap between the face shield and the forehead will help reduce the chance of liquid splash to the eyes
- It is important that the face shield extends down below the chin and stretch around the full-face area
- Designs that use compression to attach the face shield to the face were observed to be promising

From a design perspective, for the skin to frame interface, it is desired to maximize frame/skin interface surface area to provide enhanced splash protection along with a foam interface for a comfortable seal. For the location of the window, it is desirable for full face protection with extended facepiece length to provide protection from both front and side splash events. Design for multiple reuse options by leveraging material properties for improved compatibility with known disinfects and solvents.