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## 2015 AFRL University and Service Academy Design Challenge

Andrew P. Killmeyer  
apk13@zips.uakron.edu

Jacob Stein

Casey Hale

Jeff Quartermaine

Kevin Rolik

*See next page for additional authors*

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**Author**

Andrew P. Killmeyer, Jacob Stein, Casey Hale, Jeff Quartermaine, Kevin Rolik, Brandon Null, Nick Tsangeos, Marissa Seeley, Sam Moats, Nicholas Garafolo PhD, and Daniel Slattery

# 2015 AFRL University and Service Academy Design Challenge

## The University of Akron



Back (Left to Right): Jacob Stein, Casey Hale, Jeff Quartermaine, Kevin Rolik, Brandon Null  
Front: Nick Tsangeos, Marisa Seeley, Sam Moats, Brendan Jones, Dr. Nicholas Garafolo (Advisor)  
Not Pictured: Andrew Killmeyer and Daniel Slattery

## Executive Summary

The University of Akron's Air Force Research Laboratory's Design Challenge Team has engineered a Heat Stress Prevention Kit that includes a facial mask in which the soldier will cool down from the inside out by breathing in the cool air circulating throughout the mask. This cool air is produced from a thermoelectric chip, which has a specific temperature difference on either side, one hot and one cold. Each of the sides are isolated from one another and with the combination of heatsinks, fans, and the simple process of breathing, a system is created by inhaling cool air. The entire system is powered and controlled by a power source including two LiPo batteries, an Arduino Uno Circuit Board, and a relay all encased in an external pouch which can attach to any Molle strap system. A bonus feature to this mask system is it can be turned into a Hypothermia Prevention Kit by switching the wires or the voltage of the thermoelectric chip. The process for how the system of the mask works is shown below in Figures 1.

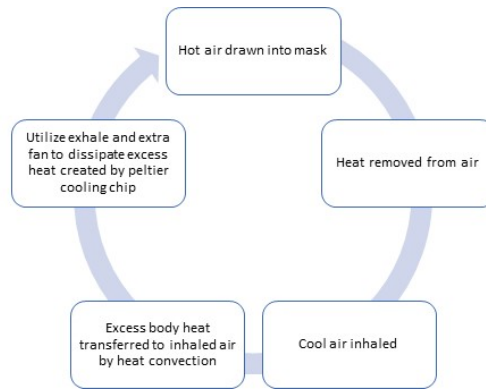


Figure 1

## Scoring Metrics

Metric	Description	Quantity	University Team's Opinion
Total Weight (lbs)	All equipment that will be on test subject the day of the competition	2.5lbs	[REDACTED]
Size (in3)	All equipment combined	128 in3	
Time (hrs)	Time device works with only above equipment	2 hr	
Device Performance	Does it help solve the problem?	[REDACTED]	7
Usability	Does it hinder movements?		7.75
Reusability	Can I just swap out power source and continue? Or do I have to wait a long time? Or do I need special equipment to recharge?		9
Innovation and Creativity	How creative do you feel your design is?		10

## Functional Overview

This cooling facial mask is used to cool the air the soldier or the airman consumes on the inhalation of the respiratory cycle. The cooler air is then taken into the body where, due to the temperature differential from the air to its surroundings, the heat is then transferred through convection from the surface of the trachea and lungs to the air. This heated air is then expelled from the body and the cycle resets with more cool air from the mask.

This mask is powered by an Arduino Uno Circuit Board, a relay and two external batteries. The circuit board is powering a thermoelectric chip, also known as a 'peltier chip'. This chip creates a specific temperature difference on either side due to its material properties when a voltage is supplied across it. Internally, the mask is split into three enclosed sections, isolating the two different temperatures on either side along with the intake/exhale chamber. The hot side of the peltier chip is isolated from the cold side and is exposed to the outside environment through ventilation in the mask. To keep from becoming too hot, a fan will be blowing air over the heatsink to prevent it from overheating; the user's exhale breaths will also be a form of air circulation. The cold side is also isolated but not exposed to the outside environment through the use of one-way respiratory valves from a standard particle respirator. This is the chamber that the soldier will be breathing in to keep their core body temperature down. A heatsink is attached to the cold side as well to better distribute the temperature. Figure 2 shows the airflow through the mask as well as the general temperatures of the air in relation to the ambient air.

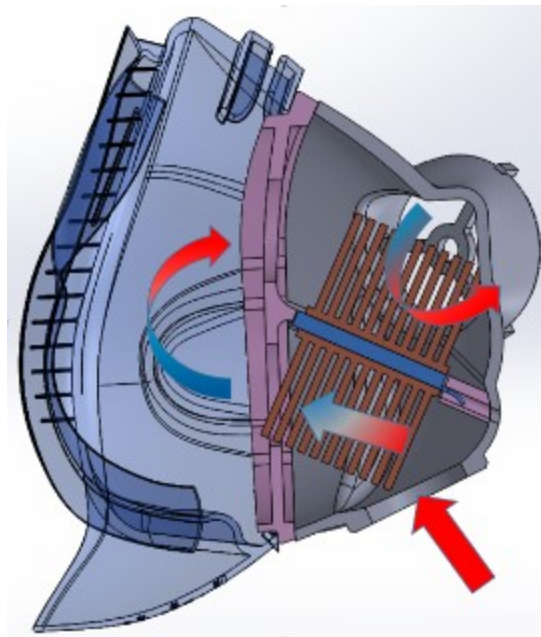


Figure 2

A major advantage to this project is with a simple switch of two wires or a voltage, this mask can be turned into a Hypothermia Prevention Kit, now having the soldier breath in warm air and keeping the soldier warm from the inside out during cold weather missions. Moreover, the fan would not have to be used in this case which removes the noise produced by the fan. Consequently, the battery used for the fan would not be needed which also would lighten the overall weight of the device, or allow for an extra battery to be taken on mission.

### **Peltier Chip**

Thermoelectric chips, also known as peltier chips, convert a voltage into a set temperature difference between the two sides of the chip. This device was chosen for our design because of their small size and portability and their inherent temperature difference that can be taken advantage of for cooling and/or heating purposes. The peltier chip specifically used for our mask is 40mm x 40mm x 3mm and has electrical specifications of 12V and 5.8A as designated by the manufacturer. These specifications can differ depending on the application. Heatsinks are used on both sides of the chip for optimum performance. These heatsinks are copper, as research and testing concluded that copper's high thermal conductivity performs most efficiently for our application.

These peltier chips were ideal for this project. The chip itself only weighs a few ounces and the basic system requires no moving parts to function. During testing it was found found that a fan was needed

to improve the thermal dissipation from the hot side of the chip in order to keep the size and weight of the heatsink to a minimum.

## **Power Solution**

Unlike traditional batteries, Lithium Polymer (LiPo) batteries do not contain a hard, rigid casing around the lithium-ion cell. Instead, these LiPo batteries contain each of the lithium-ion cells in a separate pouch of polymer. While sacrificing some rigidity, this concept of isolating the cells with only a polymer compound instead of a metallic casing vastly reduces the overall weight of the battery.

As with attaching any power source to a human body, there are always inherent risks and hazards. LiPo batteries do have an unfortunate flaw in the design. Since the cells are only encased within a pouch made of plastic, they are less resistive to puncture. Once the linings are punctured, the cells have a tendency to cause a chemical reaction and ignite, however, this is not instantaneous and there are clear signs that the battery has been punctured before ignition. The team has taken steps to help mitigate the risk to the individual that will be wearing the device and reduce the possibility of the battery being punctured. We have created a box in which the two LiPo batteries, the relay, and the circuit board will be encased. This will dramatically decrease the chances for the batteries to become punctured, which decreases the risk associated with these batteries. This box will then be placed inside a pouch which is compatible with any Molle strap system.

Once the type of battery was established, the power and controls sub-team took over for the optimization of which size of battery to purchase. During testing, the power consumption was found and the subteam determined that two separate batteries were needed to reduce unnecessary losses within the electronics system. One battery would be a 2 cell, 1500mAh, and the second battery would be a 3 cell, 6400mAh. The 2 cell battery was selected to run the fan and arduino since there is less energy loss when stepping a power source from 7.4V to 5V than stepping from 12V to 5V. From there, the team compiled a list of currently available batteries and found a rough linear relation between battery life and weight of the battery. After taking the linear regression of both battery sizes, a correlation was found between the life of the system and overall weight of the system. It was decided that a slight sacrifice in weight was reasonable for additional system run time. Through the optimization scheme developed in excel, it was finalized that using batteries that weigh approximately 1.2 lbs would result in an overall run time of approximately 2 hours with the device running at 100% power for the duration of life.

## **Structural Solution**

While investigating solutions for the structure, the team initially found two feasible options. The two options were using carbon fiber or using a 3D printer. The team ultimately decided to use the 3D printing route due to the time, availability, weight, and money saved over using carbon fiber.

During the development of the project, there were several 3D printers available to the team for quick, rapid prototyping. For a large portion of prototyping, polylactic acid (PLA) was the main building material for the device. The benefits of using PLA is that it is durable, relatively cheap, and two of the three printers at the disposal of the team are capable of only printing in this material. For the final design, the main shell is built out of Accura Xtreme and the internal shelf that holds the peltier chip was printed in 5530 High Heat Resin. Both of these 3D printing materials are stereolithographic resins which not only have better mechanical properties, but can produce a much higher resolution and cleaner prints than the typical, more affordable FDM style printers that extrude a thin stream of filament to build prototypes layer by layer.

## **Testing**

Testing began by first using the VO2Max test as a proof of concept due to the standard testing procedure of the test, and the equipment that was available in The University's Exercise Science Department. It was found that there was a difference in body core temperature when breathing in air colder than the environment, and that it was also much more comfortable for the user.

We then moved forward with our testing by using a heated chamber and a bike endurance test. A space heater was used to heat the chamber. Two test variations were repeatedly performed. One of the variations consisted of the user testing while the space heater was on, but breathing in cooler air from outside the chamber (room temperature air, and then air cooled by the mask). The other variation had the

user testing while the heater was on and also breathing in the chamber's warm air. The user would ride at a resistance of 1.5kp for the entirety of the test. The user would ride at 65 rpm's for 15 minutes, then at 75 rpm's for 6 minutes, and then 90 rpm's for 9 minutes. Every minute the user would take his temperature using a tympanic thermometer and record the results. Testing was done on a group member first, and then was performed on ROTC members.

Preliminary testing yielded positive results with reduction of heat rate and a stabilization of core body temperature of the individual performing the tests. In Figure 1 in the appendix, it can be seen that there was almost a 20 bpm drop in the test subject and in Figure 2 after the 7-8 minute mark, without the mask, the body temperature continues to rise but while wearing the Version 2 (V2) Mask, the body temperature appears to stabilize. This helps to support the notion that breathing in tempered air will decrease the effort needed to complete a similar task done without that tempered air. The team will continue testing on ROTC individuals and will have additional data by the competition date.

Before sending the final design to The Technology House for printing, some members of the team met with a senior ROTC cadet for advice and suggestions for improving our design. Weapons manipulation and integration with other military gear for enhanced compatibility were discussed. The ROTC cadet was able to provide excellent insight into the situations that he and his classmates have come across and where and how this device will both help and hinder those specific cadet exercises.

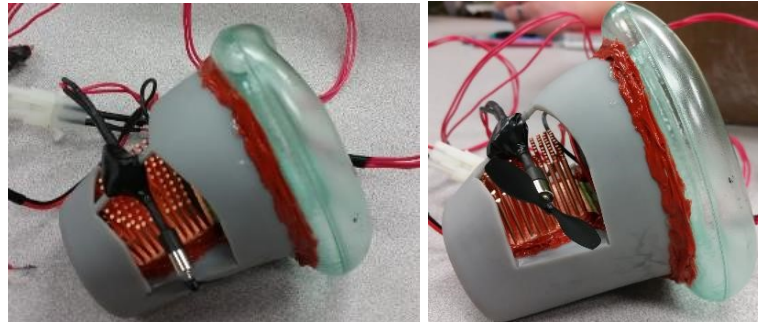
## Risks

Within our Heat Stress Prevention Kit, there are risks involved that need to be addressed to the user. The main risks are in the chart below along with their solutions or precautions taken to avoid them to begin with. The main precaution taken is by having relays and temperature sensors within the system to shut the system off if it reads a temperature value above or below temperatures that have been established through testing. The following four risks are the most critical risks to the soldier wearing the device during missions.

RISKS	PRECAUTIONS/SOLUTION
Failure of Arduino Circuit Board	Relays and temperature sensors placed within the system to shut the system off
Explosion of an overused or punctured battery	Will be placed away from head and insulated for protection
Breathing in extremely cold air	temperature sensor placed on cold side to restart system if too cold
Melting of mask from hot side of chip	Insulation and power controls with temperature sensor to shut off if overheating occurs

Other possible, less crucial risks include freezing of cold side of chip, condensation collecting on either side from moisture of breathing, failure of valves on either side of the mask, failure of headstrap, possible interference with firearm scope, and wires getting caught. During development, the team continued to try and mitigate these risks as much as possible. The power and controls sub-team added temperature sensors in order to reduce the chance of the peltier chip from reaching critical melting temperatures. Also the wires will follow the jawline strap to the back of the head and will be tucked in the soldiers vest as they travel to the electronics housing. As stated earlier, to mitigate the risk of the batteries, the batteries will be placed in a housing with the device controls that will be attached to the soldier's upper torso.

## Iterative Design Optimization



Version 1

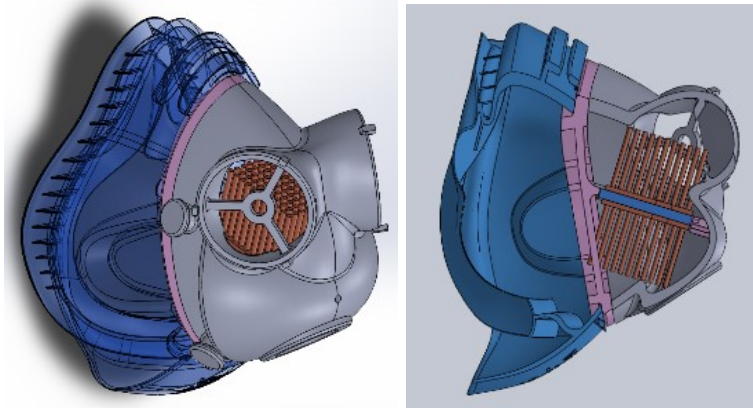
The initial design was intended to provide proof of concept. This helped to prove that the thermoelectric cooling system would provide an adequate amount of cool air to alleviate the stresses induced by inhaling too warm of air. In addition, the first iteration of the design was used as a learning tool to show, not only where the design had difficulty, but it also showed how the team as a whole was able to work together and what it would take to complete the next iterations. As testing began on this version, it came to light that there was not enough heat convection supplied by the exhale and a static system, this prompted the team to include a fan in the further designs. Another shortcoming of this design and a major concern for the success of the project was the airflow through the mask. To keep each chamber isolated, snorkel valves we used. It was found that this was insufficient for exercising so the team attempted to manufacture custom valves for the inlet and outlet.



Version 2

In this intermediate stage of development, the team focused on increasing the total heat dissipation from the hot side heat sink in order to maximize the difference in temperature between the two sides of the peltier chip. Consequently, the fan size was trimmed down in comparison to the first iteration, and the fan blade was ducted to optimize the airflow and also act as a safety feature. Moreover, a second fan location was installed for symmetry and also to provide more cooling power for the hot side heat sink. In addition, the team was also focused on ensuring a tight seal between the mask and the user's face. A Hans Rudolph VO2Max mask was selected to be used for its face sealant area and the head strap. Part of the mask was then removed to make way for our printed mask and its equipment. This is shown above in Version 2. The valves that were manufactured in for this iteration worked well, but the airflow was not to the team's satisfaction. For the next iteration, valves were stripped from a common particle respirator mask that have a much higher flow rate and reliability.





Version 3

The final version will be printed and assembled in the last couple of weeks before competition. The main modification made to this last version is the location and attachment of the peltier chip. In the previous version, the insertion of the peltier chip and heat sink set up had to be inserted through the face seal which was awkward and cumbersome. In this version, the Based on feedback from the team on construction and feedback from speaking with ROTC, the team feels confident in this design given the time and scope of this project. As with every project, there are always improvements and future possibilities that can be included in the design and those will be discussed in the following section.

### **Possible Future Improvements**

If money and time were unlimited, the following would have been tested and completed and is suggested to incorporate for real life usage of mask:

- 1.) Include a microphone on the inside of the mask for better communication.
  - a.) Difficult to hear user when communicating regularly while mask is on.
- 2.) Have two fans running (in same direction) to better the airflow over the top side of mask.
- 3.) Increase battery size to increase life of device for longer missions or bring extra batteries with user on mission.
- 4.) Alternative strapping to attach to a helmet instead of a strap underneath the helmet.
- 5.) Have a less spacious facial liner (the blue portion of the mask).

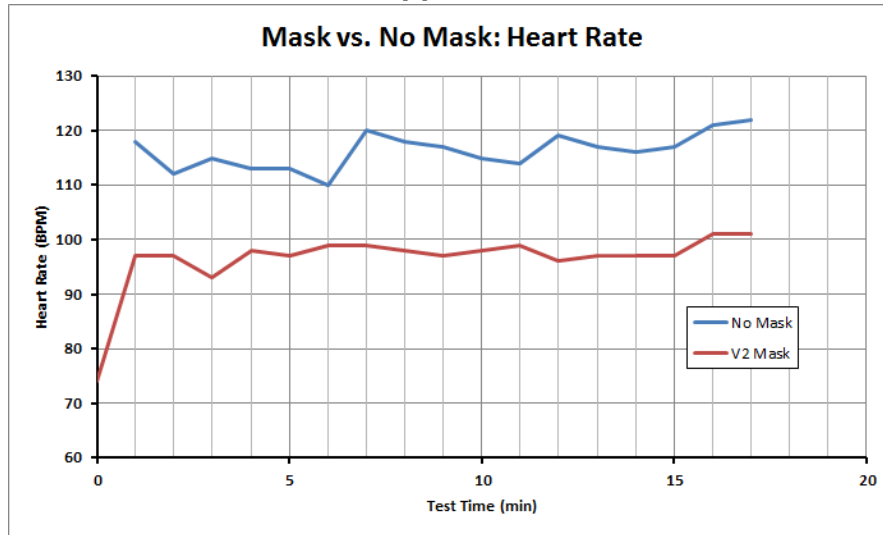
### **Acknowledgements**

As the University of Akron's AFRL University Design Challenge team, we would like to extend our appreciation to a number of different people. Firstly, we would like to extend our appreciation to The University of Akron. Without their outstanding reputation and drive to become one of the leaders in the advancement of technology, we would not be selected as one of the sixteen universities to participate in this prestigious competitions. We would also like to thank the Department of Exercise Science, in particular Scott Jameison and Dr. Otterstetter, with their help we were able to numerically quantify and analyze the human body as a system and perform our human testing. We would also like to extend our thanks to Dr. Choi, who helped assist with our 3D printing. We also thank The Technology House for printing 3D versions of our mask pro bono. Last but certainly not least, we would like to thank the United States Air Force Research Laboratory. Without their program and funding, we would not have this great opportunity as a design project, nor would we be able to travel and compete alongside some of the best universities in the nation.

## References

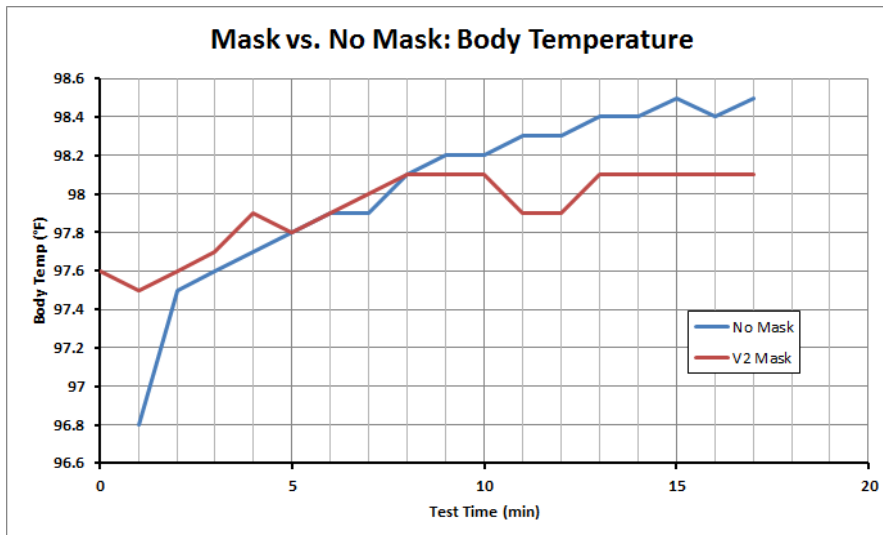
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## Appendix



**Figure 1**

Figure 1 illustrates the overall heart rate of teammate Daniel Slattery over a 17 minute period of time while riding a stationary bike. This graph shows that incorporating the mask into workouts can reduce heart rate by approximately 15% compared to exercising without the mask on.



**Figure 2**

Figure 2 illustrates the overall body temperature of teammate Daniel Slattery over the same 17 minute period of time on the stationary bike. The graph is showing that having the mask on while working out steadied the body temperature out at approximately 98.1°F, while not having a mask on the body temperature kept rising.