2020-03

A FEASIBILITY ASSESSMENT AND ANALYSIS OF ALTERNATIVES OF WEARABLE AND NON-WEARABLE COCKPIT BIOMETRICS ABOARD FIGHTER CLASS AIRCRAFT

Lambert, Emily L.; Nguyen, Jacob D.; Noronha, Sean J.; Rodriguez, Moises J.; Saint-Fleur, Marc A.; Sebacher, Kristina L.; Travis, Jazmine C.

Monterey, CA; Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

A FEASIBILITY ASSESSMENT AND ANALYSIS OF ALTERNATIVES OF WEARABLE AND NON-WEARABLE COCKPIT BIOMETRICS ABOARD FIGHTER CLASS AIRCRAFT

by

Emily L. Lambert, Jacob D. Nguyen, Sean J. Noronha, Moises J. Rodriguez, Marc A. Saint-Fleur, Kristina L. Sebacher, and Jazmine C. Travis

March 2020

Co-Advisor: Ronald R. Carlson
Co-Advisor: Rama D. Gehris

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** March 2020	**3. REPORT TYPE AND DATES COVERED** Systems Engineering Capstone Report	
4. TITLE AND SUBTITLE A FEASIBILITY ASSESSMENT AND ANALYSIS OF ALTERNATIVES OF WEARABLE AND NON-WEARABLE COCKPIT BIOMETRICS ABOARD FIGHTER CLASS AIRCRAFT			**5. FUNDING NUMBERS**
6. AUTHOR(S) Emily L. Lambert, Jacob D. Nguyen, Sean J. Noronha, Moises J. Rodriguez, Marc A. Saint-Fleur, Kristina L. Sebacher, and Jazmine C. Travis			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Physiological episodes (PEs)continue to be a top safety concern for aviators across the United States Navy and United States Air Force. At their worst, PEs can result in catastrophic outcomes for aviators and aircraft. The team sought to identify short- and long-term solutions utilizing commercial-off-the-shelf (COTS) and proprietary devices that provide both environmental and aircrew physiological measurements in real time and post-flight necessary to identify PEs. The team sought out readily available devices, along with researching Naval Air Systems Command devices in development that could potentially fulfill requirements for critical measurements necessary for accurate data analysis. A MATLAB algorithm was developed to show all suitable solutions and consisted of both COTS and non-COTS devices, which allowed for the critical measurements to be collected. The team recommends two multi-device COTS solutions for short-term implementation and a combination of COTS and six non-COTS solutions for long-term implementation.

14. SUBJECT TERMS biometric, fighter, physiological episode, cockpit, data, aircraft operations			**15. NUMBER OF PAGES** 163
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release. Distribution is unlimited.

A FEASIBILITY ASSESSMENT AND ANALYSIS OF ALTERNATIVES OF WEARABLE AND NON-WEARABLE COCKPIT BIOMETRICS ABOARD FIGHTER CLASS AIRCRAFT

Emily L. Lambert, Jacob D. Nguyen, LCDR Sean J. Noronha (USN),

Moises J. Rodriguez, Marc A. Saint-Fleur, Kristina L. Sebacher, and Jazmine C. Travis

Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

and

MASTER OF SCIENCE IN ENGINEERING SYSTEMS

from the

NAVAL POSTGRADUATE SCHOOL
March 2020

Lead Editor: Sean J. Noronha

Reviewed by:

Ronald R. Carlson Co-Advisor	Rama D. Gehris Co-Advisor

Accepted by:
Ronald E. Giachetti
Chair, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Physiological episodes (PEs) continue to be a top safety concern for aviators across the United States Navy and United States Air Force. At their worst, PEs can result in catastrophic outcomes for aviators and aircraft. The team sought to identify short- and long-term solutions utilizing commercial-off-the-shelf (COTS) and proprietary devices that provide both environmental and aircrew physiological measurements in real time and post-flight necessary to identify PEs. The team sought out readily available devices, along with researching Naval Air Systems Command devices in development that could potentially fulfill requirements for critical measurements necessary for accurate data analysis. A MATLAB algorithm was developed to show all suitable solutions and consisted of both COTS and non-COTS devices, which allowed for the critical measurements to be collected. The team recommends two multi-device COTS solutions for short-term implementation and a combination of COTS and six non-COTS solutions for long-term implementation.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACC	air combat command
AOA	analysis of alternatives
AOS	aircrew oxygen systems
AWARE	active wearable for assessment and remote evaluation
COTS	commercial-off-the-shelf
DIU	defense innovation units
DOD	Department of Defense
ECG	electrocardiography
ECS	environmental control system
EEG	electroencephalogram
EMG	electromyography
EMI	electromagnetic interference
FMS	foreign military sales
G-Force	gravitational force
GPS	global positioning system
H2S	hydrogen sulfide
HAMS	hypoxia alert and monitoring system
HL-PE	hypoxia-like physiological event
HMAPS	holistic modular aircrew physiologic status monitoring systems
HRM	heart rate monitor
HRV	heart rate variability
HR2	heart rate recovery
IRB	institutional review board
JHMCS	joint helmet-mounting cueing system
JPEAT	joint physiological episodes action team
LED	light emitting diodes
LEL	lower explosive limit
LOX	liquid oxygen
MASES	fiber optic flight mask sensor system
MATLAB	matrix laboratory
MICROS	miniature integrated circuits reporting overall status

NAMRU-D	Naval Medical Research Unit Dayton
NAVAIR	Naval Air System Command
NAWCAD	Naval Air Warfare Center Aircraft Division
NAWCADPAX	Naval Air Warfare Center Aircraft Division Patuxent River
NIRS	near-infrared spectroscopy
OBOGS	onboard oxygen generating system
OEM	original equipment manufacturer
PC	personal computer
PE	physiological episode
PEAT	physiological episode action team
PMA	program manager aircraft
PPAS	pilot physiologic assessment system
ppCO2	partial pressure of carbon dioxide
PPE	personal protective equipment
RFI	request for information
SE	systems engineering
SEM	sensor electronics module
SME	subject matter expert
SpO2	peripheral capillary oxygen saturation
TMS	type/model/series
TRACOM	Training Command
USAF	United States Air Force
USB	universal serial bus
USNI	United States Naval Institute
USN	United States Navy
VOC	volatile organic compounds
VX-31	Air Test and Evaluation Squadron Three One

EXECUTIVE SUMMARY

In an effort to support the mitigation of physiological episodes (PE) often observed in the dynamic tactical aviation environment, the team in 2019 conducted a study to evaluate commercial-off-the-shelf (COTS) and Naval Air System Command (NAVAIR) developed solutions for use as aircrew and cockpit monitoring devices. The use of these monitoring devices equips the aircrew with improved awareness to assess physiological symptoms during flight that would otherwise, compromise the mission, aircrew safety, and aircraft safety if left unnoticed. The team identified cockpit environmental measurements, aircrew physiological measurements, and operational environments to safely monitor PEs pre-, during, and post-mission. An analysis of alternatives (AOA) study was conducted to analyze and evaluate the feasibility of these solutions in terms of individual or multi-configured COTS and NAVAIR developmental solutions arrangements to consider for testing and potential integration and implementation into the fleet. The results are allocated into two recommendation groups, immediate and long-term solutions. The recommended immediate solutions contain only COTS devices for implementation while the long-term solutions consist of both COTS and NAVAIR-developed solutions. The AOA concluded that a sole COTS solution or individual NAVAIR developed solution by itself would be insufficient. Instead, the results of the study favor a combination of solutions to capture all cockpit and aircrew measurements. This resulted in more than one recommended immediate solution and long-term solution for implementation and further testing. The team concluded the study with final remarks that identify necessary future work of the recommended immediate and long-term solutions. This was to identify and address the constraints and requirements that are out of scope for this study. One major constraint identified was the limited data on cost of the devices and thus an evaluation is recommended on the solutions for feasibility in terms of total costs for implementation purposes. It is also recommended to perform further testing for operational feasibility in a dynamic flight environment, operational compatibility, shock and vibration, security risk or violation, interference with avionics and weapons system, cyber security risk of wireless data transmissions, and proper placement around other devices to ensure that the product

is producing accurate and reliable data. The conclusion of this study also expresses the necessity for future endeavors to investigate wearable bio-sensing garment advancements as well as evaluate the interoperability of physiological monitoring technology. As PEs are not limited to a single aircraft or Type/Model/Series, an evaluation for interoperability of the solutions support multiplatform efforts to mitigate PE.

ACKNOWLEDGMENTS

A special acknowledgement to LT Angela Roush for her indispensable help in creating our matrix laboratory (MATLAB) code and her continuous support as a sounding board.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION AND BACKGROUND

The United States Navy (USN) has utilized power projection methods over the course of the service's history, from the early days of battleships to the current utilization of naval aircraft projected from aircraft carriers. The air arm of the USN currently has over 1,000 aircraft that operate on aircraft carriers or in support of maritime roles from air bases throughout the world. Piloting these state-of-the-art weapon systems are naval aviators who spend years training to employ their respective platforms and, if called upon, employed in combat roles throughout the world. The aircraft flown by the USN are also flown by other air forces throughout the world through the foreign military sales (FMS) program. As such, the discussion in this paper also has meaningful impact on aircrew in FMS countries such as Australia, Spain, Canada, and several others that are considering purchases in the future.

These aircraft and their aircrew operate in a wide variety of environments, from the cold Artic to the sweltering heat of the Middle East. While aircraft, such as the F/A-18 Hornet/Super Hornet and the EA-18G Growler, are flown to the edge of their designed operating envelope, the human body is not built to operate in these conditions. It can take years of experience before aircrew are proficient in their weapons systems and have a high likelihood of returning from a combat mission safely. Unfortunately, some aircrews have lost their lives trying to do just this as a result of underestimating their body's capability and the ways it can change from day to day due to the flight environment in which they are operating. There are significant challenges to producing an aircraft that can account for every individual qualified to fly it and their unique physiology. The onboard oxygen generating system (OBOGS), the environmental control system (ECS) and their respective built-in "device health monitoring" systems, are all utilized to keep aircrew comfortable, alert and coherent while flying their missions. The following sections contain a discussion of the definition of a physiological episode (PE) and the role of the ECS and OBOGS.

A. PE DEFINITION

The Navy has defined PE as incidents in which aircrew experiences loss in performance due to insufficient oxygen, depressurization, or other factors during flight leading to symptoms of hypoxia, decompression illness, acapnia (a deficiency of carbon dioxide in blood and tissue), and more (SECNAV 2017). At their worst, PEs have resulted in the loss of aircrew, aircraft, and permanent or partial disability for the affected aviators. In recent years, the USN listed PE as the number one safety issue affecting naval aviation. These PEs have affected multiple type/model/series (TMS) aircraft, including FA-18, EA-18G, T-45 and various other United States Air Force (USAF) models. To name a specific example, F-22 pilots experienced hypoxia incidents, one of which resulted in a fatality, that spurred a temporary stand-down order by the Air Combat Command (ACC) on May 3, 2011 (Trimble 2011). Over the years, a dramatic rise in incidents—including the well-publicized and unprecedented training command (TRACOM) instructors refusing to fly in the T-45 community (Joyner 2018)—led the Navy to do a full investigation on the root cause of PE. The culmination of these events led to the necessity of monitoring devices in support of PE mitigation.

These PE events are the number one safety concern in the naval aviation fleet (Joyner 2018). Since 1991, the number of events has become more and more prevalent. In a PE comprehensive review conducted by NAVAIR in 2017, the authors state that the increased number of reports can be attributed to the greater awareness throughout the fleet (Navy Office of Information 2017). The first spike in reports occurred from 2000–2009, when there were over 101 reported events, the second occurred from 2010–2017 when there were 497 reports (Navy Office of Information 2017). These reports included numerous aircraft types including the FA-18 aircraft. According to the Naval Safety Center Reports, these reports were documented as hypoxia-like physiological events (HL-PE) and PEs are often related to ECS and cabin pressurization malfunction issues. According to an article by the United States Naval Institute (USNI), when components in the ECS fail, it can cause air pressure fluctuations in the cockpit, which is tied to the OBOGS in the cockpit. Similar issues have been found within the T-45 trainer aircraft (Eckstein 2019).

In 2017, NAVAIR established the physiological episode action team (PEAT) in order to coordinate cross community efforts within the naval fleet. In 2018, the effort was taken a step further when the joint physiological episodes action team (JPEAT) was introduced to coordinate efforts between the Air Force and the Navy. This team was established since similar issues have plagued the F-15, F-16, F-22, and F-35 related to failures in the ECS. Since establishment, there has been research conducted on the maintenance interval of the ECS and potential air contamination as well as COTS solutions for PE monitoring (Joyner 2018).

Along with the heightened awareness of PE and events, there was also an increase in reports from aircrews and their HL-PE experienced during flight. As suggested by other research, the root cause of the PE issues seen are difficult to determine, and the initial cause was thought to be the OBOGS and liquid oxygen (LOX) systems. The reason for this is that these systems support the operator's respiration and the events that were caused by respiratory issues were due to the reduced levels of carbon dioxide found in the operator's blood after flight (Phillips, Warner, and Geyer 2016). The ECS and the OBOGS system have been viewed as the most likely causes of many of the PEs in the naval fleet. In an article by USNI, after adjustments were made to the ECS system, the number of PEs was reduced by 50 percent in the FA-18 (Eckstein 2017). According to Admiral Mike Shoemaker, "It is unlikely that PEs will ever go away, they are more focused on being predictable using data analytics and better maintenance on the aircraft" (Eckstein 2019, 8).

These PEs have been an on-going problem for many years. While work has been done to mitigate the risk to aircrews and naval aircraft, further research needs to be done to create solutions that will monitor the cockpit environment and monitor the aircrew to ensure their health is not compromised under dynamic tactical aviation environments.

B. PROJECT OVERVIEW

The team evaluated currently available for purchase or soon to be available for purchase COTS solutions and NAVAIR developed solutions for use as aircrew and cockpit monitoring devices. The team will then conduct an AOA on combinations of these solutions to identify the most promising options. The goal of this effort is to identify biometrics and sensors to monitor the cockpit environment and the human state for conditions that may be detrimental to mission accomplishment.

1. Project Objective

The overall objectives of the project are to identify possible COTS, prototypes, and NAVAIR-developed solutions that in some combination provide both cockpit environmental and aircrew physiological measurements in real time and available post-flight necessary to identify PEs. The proposed solutions are analyzed with the intent to provide recommended combinations of solutions to the program manager aircraft (PMA) for testing.

This report will aid in providing different solutions that may contribute to NAVAIR's developmental efforts to support the safety of the aircrew and aircraft. During the course of the project, the team answered these questions:

1. What biometrics/environmental data would be the most beneficial to collect during aircraft operations?
2. What technology is available for easy incorporation into a fighter aircraft?
3. What can be incorporated into a cockpit environment without effect on flight operations or egress?
4. Which combinations of devices would perform well together and capture the required information?

2. Scope

The top priority of this capstone is to ensure that the reviewed devices do not increase aircrew and aircraft safety risk. The team objective was to ensure that the devices presented would not interfere with the safety of the aircrew or of the aircraft. These requirements drove the development and utilization of the safety survey for the capstone. Another aspect deemed within scope revolved around physiological and environmental measurements ultimately drove the characteristic evaluation of the devices. The design intent focuses on the design purpose. The intended use of the device will be in an aviation setting. The team favors the devices made for operation in the cockpit environment over those designed for other purposes, (e.g., fitness sportswear and monitoring) because they were designed specifically to operate in the environment unique to a cockpit. The team explored devices that monitor physiological and environmental measurements, but will not prevent or mitigate PEs. The concept map (Figure 1) shows the scope of factors evaluated for the project. The inside of the oval represents considerations within the scope of the capstone effort. Outside of the diagram are specific topics that are outside of the scope of the capstone and are explained below.

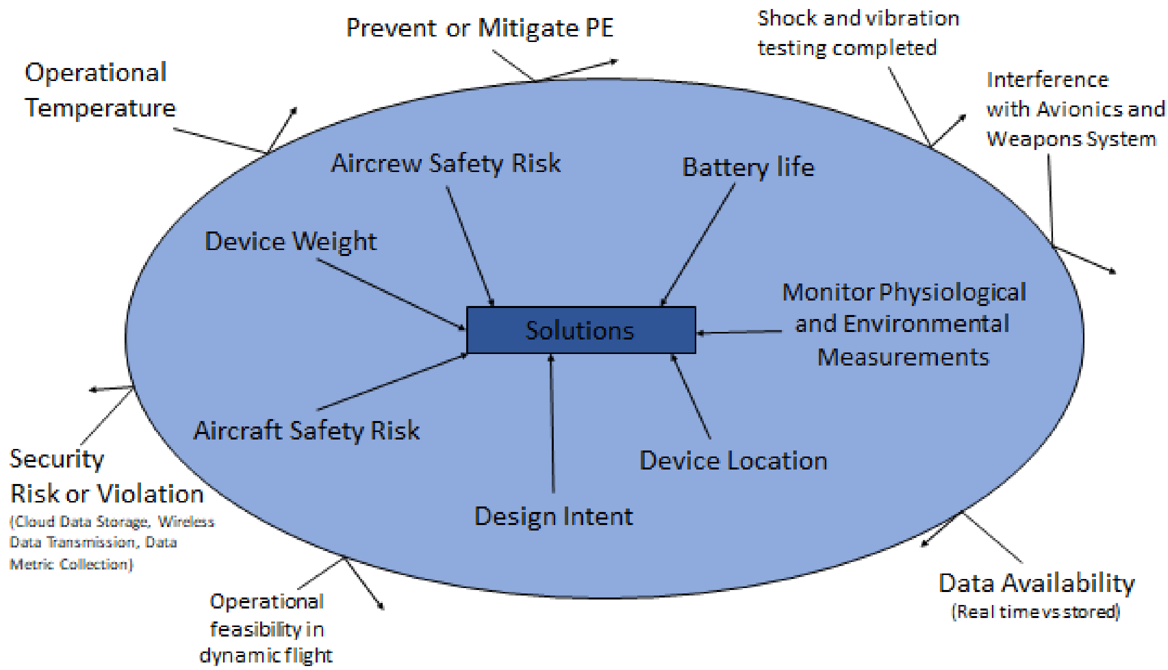


Figure 1. Concept Diagram

This concept diagram is derived from several technical assumptions and constraints, detailed in tables 1 and 2. These constraints directly affect this project's ability to define a long-term solution for the Navy. This is because there are constraints that limit the ability to test available devices. Physiological monitoring devices require an extensive amount of time and funding to be developed, tested, and tailored to meet the requirements to operate in such an environment. Due to the long lead-time to produce results from developmental efforts, individual or stand-alone COTS devices are identified as short-term solutions that can meet partial or minimum requirements until NAVAIR's development efforts have come into fruition. These short-term solutions, although not robust in design, will be able to provide a higher level of awareness to increase the aircrew's chances of detecting physiological symptoms. Some of the research currently underway by NAVAIR is still in the developmental phase. These devices under development are considered long-term solutions the Navy needs.

We assume all identified devices can operate in the dynamic environment unique to a fighter aircraft cockpit. This requires operation in fluctuating barometric pressures, electromagnetic interference (EMI) from aircraft avionics, and fluctuating temperatures and airflow rates. Additionally, there are requirements set by the Navy for safety of the aircrew and the aircraft as well as requirements set to preserve any potentially secure information. This aviation environment provides a challenge unlike that for commercially developed devices. As these considerations are not typical for COTS biometric monitoring systems, making them requirements for consideration in this study will eliminate most, if not all solutions. The factors that were deemed outside the scope of consideration were removed due to the lack of reliable information.

Table 1 lists the assumptions for this project. These assumptions are expected events or conditions that will be pertinent during conducted research.

Table 1. Assumptions

Assumption #	Description
1	The responses to the safety survey will be honest feedback.
2	All NAVAIR developed devices meet go/no-go requirements.
3	All NAVAIR developed devices are assumed safe for crew operations and egress and are therefore not subject to aircrew assessment.
4	All devices that measure a given biometric or environmental measurement are equally good at collecting said measurement.
5	All devices are able to operate in the dynamic environment.
6	The device's location on the body will support the ability to accurately monitor the physiological and environmental measurements.
7	Maintenance support will be addressed upon implementation and will not be discussed here.
8	Supply chain and support logistics will be handled by the program office and will not be addressed.
9	All operation and life cycle sustainment plans will be handled by the program office or squadron and will not be discussed here.

Table 2 lists the constraints for this project. These constraints are limitations imposed on the capstone project.

Table 2. Constraints

Constraint #	Description
1	This study is constrained to the available technology on the market (COTS), prototypes, and NAVAIR developmental devices as of October 2019.
2	COTS solutions identified will be the most current innovation at the time this Capstone project is conducted.

3. Requirements

Table 3 and Table 4 detail the in-scope and out of scope requirements identified in the context diagram. The requirements in Table 3 fall within the capstone project scope.

Table 3. In- Scope Requirements

Requirement #	Requirement	Description
1	Aircrew Safety Risk	A device shall not negatively affect the safety of aircrew.
2	Battery Life	A device shall hold its charge for its intended purpose for at least 10 hours (Go/No Go Requirement).
3	Aircraft Safety Risk	The integration of devices shall not compromise any other system within the cockpit or each other
4	Physiological and Environmental Measurements	A device shall capture at least one of the following measurements: heart rate, body temperature, oxygen intake, oxygen output, carbon dioxide output, breathing rate, blood oxygen level, temperature, humidity, air quality/composition, and gravitational force (G-force) (Go/No Requirement).
6	Device Location	A device shall not hinder aircrew's ability to perform tasks.
7	Device Weight	The weight of each device shall not affect the aircrew's ability to fly the aircraft and complete the required mission.

1. Aircrew Safety Risk

Aircrew safety focuses on the safety of any personnel that operates inside an aircraft cockpit. If a device hinders the aircrew's ability to perform essential tasks, they will be eliminated. The devices must also not negatively affect the aircrew during their mission.

2. Battery Life

Battery life is a necessary consideration when identifying possible solutions to prevent physiological events. Utilizing information from LCDR Noronha, a pilot on the E/A-18G and the team's lead editor, the team noted that while normal training flights are only an hour or two in duration, flights in a combat zone are typically longer and usually between six to seven hours in duration. By ensuring that the battery life is longer than a flight, the device will be able to capture all necessary data without losing any segments.

3. Aircraft Safety Risk

The integration of the possible solution shall not compromise any system within the cockpit. This can result in a loss of military assets and personnel.

4. Physiological Measurements

These measurements are needed to quantitatively measure the signs of PEs. Further discussion why these specific measurements were chosen is provided in Chapter IV.

5. Environmental Measurements

These measurements are needed to quantitatively measure the signs of PEs. Further discussion why these specific measurements were chosen is provided in Chapter IV.

6. Device Location

Where the device is located on the body is important because the location of the device can affect the response time and accuracy of the device. The more accurate the reading on the body, the more reliable the reading of the measurements the device can detect. It is also possible that some devices in certain locations can affect aircrew's movement and their ability to perform their necessary tasks. Due to the aircrew's configuration of gear, integration of some COTS items will make it difficult to obtain accurate data. For example, there may be difficulty obtaining data from the chest due to aircrews possibly flying with a jerkin (Air Force), survival vest, or cold-water immersion suits. F/A-18 and E/A-18 aircrew and other Navy operators wear a seatbelt, survival vest, and cold-water immersion vests that can negatively affect the signal to noise ratio (Phillips, Warner, and Geyer 2016).

7. Device Weight

Device weight, coupled with device location, can hinder aircrew's ability to accomplish their tasks.

The following requirements were also considered and deemed important, but are not within the scope of this capstone project. Resources beyond the scope of this project would be needed to test these requirements.

Table 4. Out-of-Scope Requirements

Requirement #	Requirement	Description
8	Operational Feasibility in Dynamic Flight Environment	The device shall have the ability to operate under dynamic flight environment such as varying barometric pressure, altitude, G-force.
8.1	Operational Temperature	The device shall operate between the temperatures of 30 to 95°F.
8.2	Shock and Vibration	The device shall pass shock and vibration
9	Operational Compatibility	The device shall not interfere with aircraft mission capabilities.
9.1	Interference with Avionics and Weapons System (Electro-magnetic Interference)	The device shall not cause interference to the rest of the avionics equipment and weapons systems in the cockpit.
10	Security Risk and Violation	The device shall not have the capability of storing and collecting data on the cloud for third party use.
10.1	Wireless Data Transmission	The device shall not wirelessly transmit data that will sends the data collected during the flight to a remote location outside of the aircraft.

8. Operational Feasibility in Dynamic Flight Environment

Due to altitude change resulting in varying barometric pressure many COTS devices are developed to be able to provide sensor data at ground level, (i.e., gas sensors) (Phillips, Warner, and Geyer 2016). According to MIL-E-18927, General Requirements for Aircraft Environmental Control Systems, the cabin pressure experienced by fighter and attack aircraft are observed to be from 0 PSI (sea level) to 5 PSI differential of the pressure outside the cabin at altitudes: 23,000 feet and above (Department of Defense 1983). Maneuvers resulting in gravitational maneuvers cause high vibrational forces on the aircraft and operator as well as the COTS device, which causes readings to be difficult to capture. The pulse oximeter is an example. This device measures blood saturation, but it is sensitive to changes in the environment. In order to operate properly, the oximeter must be able to identify stagnant hypoxia due to G-forces or loss in oxygen supply. The report states that pulse oximeters and CO-oximeters are susceptible to false alarms due to desaturation of blood associated with G-forces leading to stagnant hypoxia. Stagnant hypoxia as defined by Naval Medical Research Unit Dayton (NAMRU-D) report is “associated with a loss of blood perfusion to the head and extremities.” In addition, anti-g muscle straining maneuvers will affect the accuracy of wearable COTS for physiological monitoring as isometric muscle contractions can affect electromagnetic and pulsatile flow signals accuracy.

8.1. Operational Temperature

According to MIL-E-18927, General Requirements for Aircraft Environmental Control Systems, under normal operating conditions, the cockpit of an aircraft can range between 30 to 95°F (DOD 1983).

8.2. Shock and Vibration

The dynamic environment of fluctuating G-Forces is unique to aviation and devices not specifically designed for aviation will not record properly. The vibration during flight causes background noise, which causes issues when trying to isolate a signal. An example of this is a pulsatile flow signal on the pulse oximeter. The device is incapable of separating the PLS from the background vibrations (Phillips, Warner, and Geyer 2016).

9. Operational Compatibility

Different platforms have their own respective criteria to what is authorized to be used on the aircraft due to different mission capabilities. This can directly affect what the aircrew wears and uses under aircraft operation (Phillips, Warner, and Geyer 2016).

9.1. Interference with Avionics and Weapons System (Electro-magnetic Interference)

EMI effects electroencephalogram (EEG), electrocardiography (ECG), and electromyography (EMG) in the cockpit, due to high electromagnetic interference results in a decreased signal to noise ratio in all bioelectrical signals that a system is designed to isolate. This runs to risk of interfering with avionics and weapon systems within the aircraft. NAVAIR tests the control of EMI characteristics of subsystems and equipment to the MIL-STD-461F, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment (Department of Defense 2007).

10. Security Risk or Violation

There is the possibility of security risk or security violation, since most devices today have cloud data storage and data metric collection. This could be a security risk or violation because the device could record or store data of the aircraft environment that the Navy might not want known publicly; it can be considered classified information. Many companies collect user data for internal metrics. This data could inadvertently lead to significant data breaches and directly affect the safety of the mission.

10.1. Wireless Data Transmission

Wireless data transmission sends the data collected during the flight to a remote location outside of the aircraft freely. Use of wireless data transmission can introduce cyber security risks that can potentially share personal information in an unsecure environment.

4. Stakeholders

Organizations that would benefit from this study include Aircrew, NAVAIR, PMA-265, PMA-273, and PMA-202. Aircrew encompasses aviators that fly F/A-18, EA-18G, and T-45 systems, both in the USN as well foreign militaries that utilize those platforms.

II. REVIEW OF PRIOR EFFORTS AND WORKS

As stated in Chapter 1, the ECS and the OBOGS system are known as the most likely causes of many of the PEs in the naval fleet. Although they are key to mitigating PE in naval aviation, ECS/OBOGS are only system-centric devices that vary depending on TMS of naval aircraft. In reacting to physiological events that can be caused by failure of the ECS and OBOGS system as well as long term solutions that combine COTS and NAVAIR developed solutions, the team determined that there needs to be other options to monitor and prevent PE. To reiterate, this capstone will identify short-term and long-term human-centric devices that may help the aircrew in reacting to these physiological events. The proposed solutions identified in Chapter IV were analyzed with the intent to provide recommended COTS and in-development devices to PMA for consideration, for further testing, and for potential integration. The COTS devices that will be recommended are short-term solutions that can meet the minimum requirements described in Table 3. Long-term solutions will likely need to be further tested to the requirements in Table 4 but are out of scope of this study. The rest of this chapter will identify existing efforts to research and develop human-centric devices to mitigate PEs. These dynamic requirements are detailed in Chapter I (Phillips, Warner and Geyer 2016).

A. COTS SENSOR REVIEW

A report released in 2016, Mitigation of HL-PE through (COTS) Sensing Technologies, by the NAMRU-D, details a study of COTS devices in reference to mitigating HL-PE. This study concluded that most COTS devices are not feasible to be used in tactical aviation environments. Environmental effects such as vibrational forces, EMI, barometric pressure changes, and G-forces that are common to tactical aviation environments degrade the performance of COTS technology because most were created for household utility. This report recommended two possible solutions: a long-term solution and short-term solution to mitigating HL-PE.

The long-term solution would be to integrate a three-layered approach for HL-PE mitigation that consists of:

1. Life Support System Sensors

2. Aircrew Physiologic Monitors

3. Aircrew Symptom Recognition

The report states that this will take years to deploy and investigate, which is why a short-term solution is proposed. For long term, we need a more robust reflectance oximetry device that should be developed by biomedical engineering experts with knowledge of the tactical aviation environment. As defined in the report by NAMRU-D:

> Traditional pulse oximeters, light emitting diodes (LED) are placed on one side of a finger, toe or earlobe while photodetectors are placed on the other side. The light must penetrate through tissue from the LED to the photodetector on the other side. In contrast, reflectance oximeters are designed with LEDs and photodetectors located on the same side. They work by analyzing wavelengths of light reflected off the tissue underneath the sensor, and therefore can be placed in almost any location. (Phillips, Warner, and Geyer 2016)

Essentially, a reflectance oximetry is a more robust method of accurately obtaining data and is recommended for aircrew use as a short-term solution. This short-term solution does not meet the urgency that the Navy needs in physiological monitoring as the developmental phase can attribute to long lead times in defining a solution. This should be viewed as a long-term solution. The report does not recommend the use of existing COTS oximetry systems as a viable option due to the changing environmental factors and unreliable data that can be presented from pulsatile flow signals such as fitness watches that monitor heart rate (Phillips, Warner, and Geyer 2016).

The report also goes against the use of chest straps and pulse oximetry devices (modern activity trackers – smart watches). Despite the report, today's aircrew, specifically on the F/A-18 and EA-18G, use a modern activity tracker as one of their only lines of defense for physiological monitoring. With this in mind, on the assumption of further innovation in technology, this capstone project will explore COTS devices as possible solutions as they will allow for the most expedited path forward to HL-PE partial mitigation, alleviating some concerns reflected by this NAMRU-D report. Finding a more robust substitute would be better than the current configuration until further investigations result in permanent solutions to HL-PE mitigation efforts.

B. CURRENT COTS DEVICES AND EFFORTS IN DEVELOPMENT TO MITIGATE PE – NAVAIR

The Navy has a couple of efforts in development to mitigate PE. While investigating PEs, the Navy assigned two teams to focus primarily on the aircrew or the aircraft. The aircrew oxygen systems (AOS) team at NAVAIR has focused their projects on the aircraft, while a NAVAIR Human Systems Engineering (SE) Team, under PMA-202/AIR-4.6, has focused their projects on the human aircrew. The AOS team at NAVAIR has produced many hypoxia mitigation efforts thus far. Many of their projects that will be discussed are in development, fielded, or in ongoing testing. The AOS team's efforts are system centric, but they have collaborated with the Human SE Team in NAVAIR to enable a human interfaced design, which supports physiological monitoring. The work being done by both NAVAIR teams that is currently being used to support the mitigation of PE is defined in Table 5 and will be detailed in the following paragraphs.

Table 5. Current PE Mitigation/Prevention Work to Date

Device	Description
CRU-123 solid-state oxygen monitor	Measures oxygen pressure and oxygen percentage in the T-45. The OBOGS oxygen monitoring devices give indications of pressure anomalies in the cockpit. (Joyner, 2018)
Garmin watches	COTS device that provide aircrew with real-time alerts of pressure fluctuations in the cockpit (Joyner, 2018).
SlamStick	Device used to measure cockpit pressure changes with time, rate, and amplitude. The SlamStick is not a real-time warning device; the device collects data for post-flight evaluation (Joyner, 2018).

The Garmin watches and SlamStick are both worn by the operator during flight. The SlamStick measures air pressure, temperature, and vibrations in the cockpit. The Garmin watch measures cabin pressure fluctuations and altitude and alerts the operator with a vibrating haptic feature. These units were chosen based on their ability to operate within the environment required by the mission (Phillips, Warner, and Geyer 2016). Both units are located on the person during operation to reduce the amount of interaction the individual has with the unit. The CRU-123 resides in the T-45 cockpit where it measures oxygen pressure and oxygen percentage in order to record and indicate pressure anomalies in the cockpit.

The collaboration of teams within NAVAIR to tackle a more human interfaced design approach in terms of physiological monitoring has resulted in the developmental effort of the Pilot Physiologic Assessment System (PPAS). It is a mask and hose mounted sensor system that monitors oxygen, carbon dioxide, and flow with a hypoxia detection/prediction algorithm. Another working device is the Hypoxia Alert and Monitoring System (HAMS) – that integrates physiological sensors with computer algorithms to predict/detect/prevent hypoxia (Fleet Support Team 2019). Both of these systems were deemed not acceptable by NAVAIR. The final system that NAVAIR has worked with is the Canary Pilot Health monitoring system. The Canary Pilot Health monitoring system was tested to validate operation while integrated with the F/A-18F Super Hornet. This test was conducted by Air Test and Evaluation Squadron Three One (VX-31) in China Lake, CA. This system was installed in the Joint Helmet-Mounted Cueing System (JHMCS) and "was designed to provide continuous and non-invasive aircrew physiological monitoring." The system monitored and showed the following information: heart rate, blood flow, oxygen saturation levels, cockpit barometric altitude, and aircraft acceleration. The test of the Canary System showed limitations on both the ground and in flight, and aircrew recommended that it was unsuitable to monitor for PE (Wright and Winder 2017).

As of June 2019, NAVAIR is developing, testing, and evaluating defense innovation units (DIU) and holistic modular aircrew physiologic status (HMAPS) monitoring system. The HMAPS monitoring system is still in development and aims to provide a Bluetooth ECG patch and Bluetooth EarClip that includes Pulse Oximeter and temperature sensors that connect through the HMAPS Arm Unit. The HMAPS Arm Unit includes an ECG, pulse oximeter, skin temperature sensor, environmental sensor suite, and a real-time clock to capture the data instantaneously. This data is downloaded onto a personal computer (PC) via Universal serial bus (USB) Cable/Wi-Fi for post data analysis.

There is also a dedicated team established within Naval Air Warfare Center Aircraft Division (NAWCAD) that has been investigating physiologic monitoring systems versus the system monitoring that the AOS team primarily does. Their goal of having physiological monitors is to measure the human response since physiological events happen to people not to aircraft. Some DIU technologies under investigation/development are the Nonin original equipment manufacturer (OEM), the fiber optic flight mask sensor systems (MASES), and the Mouth Molar Clip. The Nonin OEM is integrated into helmet ear cups that measure pulse rate, Sp02, cabin pressure, and acceleration while providing voice alerts, while MASES measures In-Mask partial pressure of carbon dioxide (ppCO2). The Mouth Molar Clip with Biomedical sensor suite is designed for sensor "drop ins" for rapid iteration and extension capability with the molar mic. Other notable projects outside of DIU being investigated include Sensor Garment (with ECG, respiration rate/mechanics, accelerometer), In-ear sensing with temperature and heart rate monitor (HRM), and near-infrared spectroscopy (NIRS) cerebral Oximeter. NAVAIR and PMA-202 plan to investigate all three of these devices in the near future. (Shender and Wathen 2019). Chapter IV will provide more information on these devices as they are devices in development that can be integrated with recommended COTS solutions.

THIS PAGE INTENTIONALLY LEFT BLANK

III. METHODOLOGY AND TECHNICAL APPROACH

This chapter details the methodology and technical approach used to evaluate all devices. These methods are used in Chapter IV to execute the evaluation.

A. TECHNICAL APPROACH

Figure 2 provides a map of the process that was used to define the technical approach required by the team to complete this project. The SE process described below provides more detail to this figure and provides the reader with an understanding of the steps performed during this project.

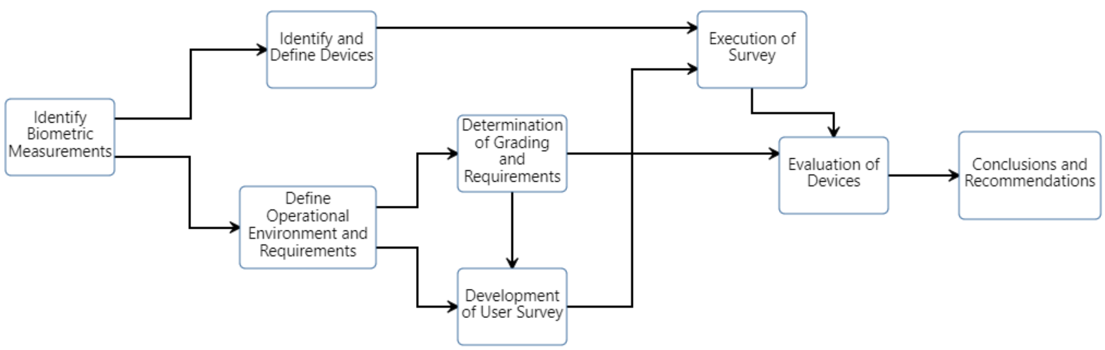


Figure 2. Technical Approach Diagram

The SE Process began with understanding the mission and stakeholder need as it relates to PE, cockpit environmental monitoring, and aircrew physiological monitoring. The team then identified cockpit environmental measurements, aircrew physiological measurements, and operational environments needed to monitor PEs pre-, during and post-mission. The SE Process led the team to utilize an AOA study to evaluate available PE monitoring technology. The AOA began with developing an AOA study plan that set the purpose of the study, the devices being analyzed, and the methods/criteria with which to evaluate the devices. The AOA was broken down into assessments to evaluate the monitoring devices; the assessments include a characteristic evaluation and a multiple configuration evaluation. In order to be considered in the AOA, a product was graded against a go/no-go evaluation and a safety survey. The devices that passed as a "go" were assessed in a safety survey. The safety survey offered the team valuable operational insight from end-users on any potential safety concerns during operation of the aircraft or egress. The feedback received from the safety survey was implemented into the AOA and the devices were graded as "safety acceptable" or "safety unacceptable." The COTS solutions that passed the go/no-go evaluation and the aircrew safety survey were then assessed on criteria implemented in a characteristic evaluation, as further discussed in this chapter. The characteristic evaluation graded each product based on the cockpit environmental measurements, aircrew physiological measurements, and requirements identified earlier in the SE process. Finally, a multiple configuration evaluation was used to help determine the optimal combination of devices within the sensor suites, which covers as many measurements as possible. The team evaluated the overall results of the AOA and offered recommendations. This process is shown in Figure 3.

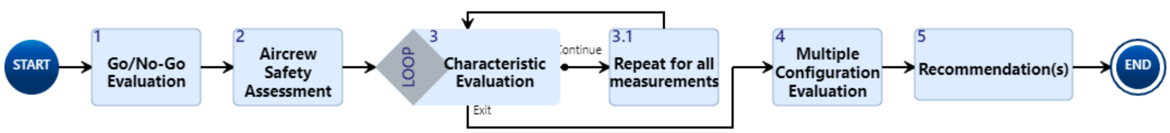


Figure 3. AOA Process

B. IDENTIFICATION OF MEASUREMENTS

The intent of each measurement is to gather data that can be used to identify physiological symptoms and environmental factors that may assist in monitoring PE. These COTS devices will be used to record these biometric measurements that aid in researching a PE or HL-PE that is triggered during flight. This provides better understanding of what the aircrew was experiencing prior/during/post PE. As detailed in Chapter II, the biometric measurements discussed were defined by the symptoms that the aircrew have seen in previous flights and investigations. The recorded measurements can provide reconstructed flight data and potential insight into PE episodes.

C. IDENTIFICATION OF DEVICES

COTS devices will be identified via one of three ways. First, existing devices currently being flown by the USN on aircraft are identified with a potential to monitor physiological and environmental parameters that may lead to PE. Second, we identify if a device can provide at least one of the identified measurements discussed later in Chapter IV. Finally, we identify the devices that are currently under development by NAVAIR specifically for the purpose of detecting, identifying, and/or reconstructing PEs.

The following information will be defined for all devices, COTS and NAVAIR developed:

- Name
- Manufacturer
- A summary description of the design intent and concept of the device, as presented by the manufacturer.
- Cost, if available
- All identified measurements that the device is capable of providing from the list of identified measurements of interest.
- All characteristic parameters as defined in the characteristic parameter portion of this chapter.

D. GO/NO-GO EVALUATION

All identified devices will be subject to a series of go/no-go requirements. Failure to meet all requirements will result in removal from consideration. The go/no-go requirements were developed to ensure aircraft safety and device operation for the duration of a flight. The requirements were previously addressed in Table 3; however, they are listed in more detail below.

The first requirement: the device shall measure one of the identified measurements (see requirement 4 and 5 in Table 3). Research was performed in order to determine the best possible measurements that needed to be captured in order to provide a good status of the cockpit and of the aircrew. The measurements and devices were also researched and defined concurrently in order to ensure nothing made it through the evaluation without giving useful data.

The second requirement: a device shall have a minimum battery life of at least 10 hours (see requirement 2 in Table 3). Long flight time missions for in-country are typically determined to be 7–8 hours. While mission length can vary based on tasking and execution, the times listed were obtained from personal experience LCDR Noronha. Having the requirement that the device have a battery life of at least 10 hours ensures that the device can take measurements for the entire flight, plus pre-flight activities between gear-up and take-off.

The third requirement: the device shall not interfere with uniform, personal protective equipment (PPE), or flight gear (see requirement 1 in Table 3). This is important because it is imperative that the aircrew can perform their required mission without any additional hindrance, which would add hazards to the cockpit. Safety is always the top concern when adding any new device into the cockpit.

E. AIRCREW SAFETY ASSESSMENT

All devices that meet the go/no-go criteria and are not ones under development by NAVAIR will be subject to an aircrew survey evaluation to ensure aircrew safety in the cockpit environment. Devices under development by NAVAIR are exempt from the evaluation as they are being designed specifically for use in the cockpit of a fighter class aircraft. As NAVAIR is the final authority for all safety assessments and flight clearances for all naval fighter class aircraft, the team assumes that these devices meet the required safety assessment.

Each device will have the same two questions asked of it:

- Question 1: Will (proposed solution) interfere with crew operations within the aircraft?

- Question 2: Will (proposed solution) interfere with egress in the case of an emergency?

Each question will have a score of 1 of 4, with 1 being no interference, and 4 being significant interference. The table will detail the total number of responses for each question for all device. For all devices, if any survey response is a 3 or higher for either question, the device will be removed from consideration.

F. CHARACTERISTIC EVALUATION

All devices that pass the go/no-go requirements and receive a score of less than or equal to 2 for both survey questions (and all NAVAIR developed devices that passed the defined go/no-go criteria) will be subject to a characteristic evaluation. The characteristic evaluation assesses the importance of what the device can measure in relation to identified measurements needed by the Navy to investigate PE. Each device received a characteristic rating for every measurement that it is capable of measuring. The characteristic rating is composed of parameters corresponding to the identified level of importance of the four device characteristics: weight, battery life, design intent, and location on body. The device characteristics will be discussed further in this chapter under section H. The result will be listed in a table of ratings with scores ranging from 0–100 based on performance of the parameter, an example of which is shown in Figure 4. Details about the scoring process are in the following sections.

	MEASUREMENTS	Heart Rate	Body Temperature	Enviro. Temperature	G Force	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	Cost	COST ($USD)	Go/NoGo Evaluation	Requirement 1	Requirement 2	Requirement 3	AIRCREW SURVEY EVALUATION	Question 1	Question 2	CHARACTERISTIC RATING	Heart Rate	Body Temperature	Enviro. Temperature	G Force
Device 1		Y	Y		Y		10	15	Aviation	Body Core		$ 100		Pass	Pass	Pass		1	1		98	70	-	70
Device 2			Y	Y			5	25	Sports	Head		$ 30		Pass	Pass	Pass		1.2	2.2		-	-	-	-
Device 3		Y	Y	Y			12	10	Medical - Stationary	Upper Limb		$ 50		Fail	Pass	Pass		-	-		-	-	-	-
Device 4			Y	Y	Y		3	30	Industrial	No Contact		$ 45		Pass	Pass	Pass		1	1.5		-	100	100	100
Device 5			Y		Y		5	30	Sports	No Contact		$ 115		Pass	Pass	Pass		1	1		-	82	-	82
Device 6		Y		Y			9	15	Aviation	Hands		$ 95		Pass	Pass	Pass		2	1		88	-	50	-

Figure 4. Example Top-Level Evaluation Matrix

As shown in Figure 4, device 3 failed the go/no-go requirement 1; therefore, no more data was processed for this device. The remaining five devices were submitted for aircrew evaluation. Device 2 was identified as a significant safety concern and was removed from consideration for the characteristic evaluation. The remaining four devices were then evaluated for the four example measurements. An example of the characteristic rating determination for heart rate is shown in Figure 5. Devices 1, 3, and 6 all measure heart rate. Device 3 was removed from consideration for failing the go/no-go requirements. Note that devices 4 and 5 do not measure heart rate, so there is no associated rating.

	MEASUREMENTS	Heart Rate	Body Temperature	Enviro. Temperature	G Force	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	Cost	COST ($USD)	PARAMETER RATINGS	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Device 1		Y	Y		Y		10	15	Aviation	Body Core		$100		90	100	100	100		98
Device 2			Y	Y								$ 30							
Device 3		Y	Y	Y								$ 50							
Device 4			Y	Y	Y							$ 45							
Device 5			Y		Y							$115							
Device 6		Y		Y			9	15	Aviation	Hands		$ 95		100	100	100	50		88

Figure 5. Example Characteristic Evaluation: Heart Rate

A scaled evaluation method is used to determine the score, relative to the devices in consideration, for a given measurement. The equations and methods for determining the characteristic evaluations are detailed in the next section.

This process will be done for each measurement until the characteristic rating section of Figure 4 is fully populated. This data will be used to inform the multiple configuration evaluation detailed later in this chapter.

G. SCORING PROCESS

Each device characteristic rating (an example of the top-level evaluation is shown in Figure 4) is calculated using the parameter ratings and is developed for each of the measurements the device provides (an example of this development is shown in Figure 5). Each of the device characteristics will be given a custom evaluation method, defined below, resulting in a parameter rating out of a possible 100. Each parameter will contribute differently to the total characteristic rating due to their identified parameter weights. The parameter weights for each device characteristic were defined by the subject matter expert (SME) on the Human SE Naval Air Warfare Center Aircraft Division Patuxent River (NAWCADPAX) team. The final score will be a sum product of the parameter rating and identified weight for the associated characteristic parameters, Equation (1.1).

$$CharacteristicRating = \sum_{CapturedMeasurements} ParamterRating \times ParameterWeight \qquad (1.1)$$

This rating is the value shown in the far-right column of Figure 5 and the results displayed in the characteristic rating section of Figure 4. Each of the four performance characteristic calculations, including the SME provided weights, is discussed in the following section.

H. CHARACTERISTIC PARAMETERS AND PARAMETER RATINGS

1. Weight (oz.)

Lower weight devices are preferred in dynamic environments of a tactical aircraft. This means that devices with lower weight are favored over devices with a high weight. Weight will be scored via Equation (1.2):

$$ParameterRating_{Weight} = \frac{MinimumParameterPerformance}{DevicePerformance} * 100\% \qquad (1.2)$$

SME provided parameter weight: 15%

Weight is an important factor to consider in the cockpit environment due to the importance of ensuring the individual is comfortable while performing their duties and not constrained to a limited range of motion. Most of these devices go on the bodies of the aircrew, but there are a few that do not. Any extra weight can hinder aircrew ability to accomplish their tasks successfully. While certain devices do not require contact with the user to collect data, they will likely still be on their person, in a pocket.

2. Battery Life (Hours)

Battery life is a high-value parameter, meaning longer battery life will result in a higher overall performance of a device. Values of 50 hours will be scored as 100. This value was chosen to be five times the go/no-go requirement and is done to keep high performers from overpowering other devices unnecessarily. Battery life performance between 10 hours and 50 hours will be evaluated via Equation (1.3).

$$ParameterRating_{BatteryLife} = \frac{DevicePerformance}{50hours} \times 100 \qquad (1.3)$$

SME provided parameter weight: 15%

Battery life is an important characteristic parameter for the aircrew because it supports the reliability and operational availability of the device. It will lower the risk of the devices running out of battery during an average mission timeframe and can allow for maximum amount of data to be collected. While the device is not essential to a flight mission, having the device functioning during a flight provides a precautionary tool that aircrew can use for extra flight safety.

3. Design Intent

As discussed in Chapter I, the usage of COTS devices limits the data available for assessing devices for suitability in a cockpit environment. In an attempt to capture the suitability, design intent will be assessed. The highest rating will be given to devices specifically designed for aviation environments. These devices were designed specifically to operate in the dynamic environment unique to a cockpit. Devices designed for athletic and industrial environments are intended to be used by a dynamic wearer, (e.g., athletes). While this design may not have taken into consideration some unique aspects of a cockpit operation, they are intended to operate under fluctuating temperatures and environmental conditions. Medical devices are broken into two categories: dynamic and static. Dynamic medical devices are intended for uses such as stress tests that are done on a dynamic user in a controlled environment. Static medical devices are intended to be used on a stationary user in a controlled medical environment. These medical devices are intended for use in the controlled medical environment of hospitals and are less likely to be able to withstand the shock, vibration, temperature, and pressure variances of a cockpit.

The parameter ratings will be as follows:

- Aviation: 100
- Industrial: 75
- Sports: 75
- Medical – Dynamic: 50
- Medical – Static: 25

SME provided parameter weight: 40%

4. Location on Body

Due to the dynamic G-forces that can occur in the cockpit of a maneuvering aircraft, the further out from the body core a measurement is measured, the more susceptible the measurement is to error and fluctuations from loss of blood flow to extremities. Where the device is located on the body is important because the location of the device can affect the response time and accuracy of the device. The more accurate the reading on the body, the better reading of blood flow and the more reliable the reading of the measurements the device can detect. Because there will be vibrational and G-forces experienced in the aircraft, the device needs to be on a location of the body that will not disrupt the signal from the device (Phillips, Warner, and Geyer 2016).

The parameter ratings will be as follows:

- Torso: 100
- Head: 100

- Upper Extremity: 75
- Upper extremity is defined as thigh and upper arm.
- Lower Extremity: 50
- Lower extremity is defined as lower arm, wrist, lower leg, or ankle.
- Any device that does not rely on contact with the operator will be evaluated as 100.

SME provided parameter weight: 30%

I. MULTIPLE CONFIGURATION EVALUATION

Once all devices have been evaluated individually for performance, sensor suites will be developed by combining devices for a more complete picture of the aircrew and cockpit environment. This was accomplished by combining devices to capture the greatest number of measurements and so that no one location on the body has more than one device.

To provide a high-level assessment of each sensor suite, a total rating was assessed using the total sum product of the characteristic rating for every measurement captured and the associated SME provided weight of each measurement. If a sensor suite captures the same measurement multiple times, the highest rating was used in the assessment. The overall rating for the sensor suite was calculated via Equation (1.4).

$$SuiteRating = \sum_{Device}\left(\sum_{Measurement}(CharacteristicRating \times MeasurementWeight)\right) \qquad (1.4)$$

This data was then coded into a MATLAB program designed to generate all possible combinations of devices and their associated rating. The printout of the results is available in Appendix D. The output of the code was broken into three categories of sensor suites: COTS and non-COTS combined suites, COTS only suites, and non-COTS only suites. They are grouped in this manner to facilitate different timeliness categories of implementation as described below. These combinations automatically include all non-contact-based solutions and utilize as many locations as possible, without duplication, to capture as much data as possible. For each of the three categories, the program created as many combinations as possible utilizing two, three, and four contact-based devices. The intent of these combinations is to provide the most comprehensive view of the aircrew and cockpit environment with the least possible devices.

From this raw data, the top performers were identified for further evaluation to narrow down the potential recommendations. Multiple factors were considered, including data redundancy, any available cost data, the importance of the measurement captured, and device availability. Duplication of measurements is not considered a negative trait. Redundancy in measurements provides a secondary source of data for data validation.

Recommendations have two categories: immediate implementation and long-term implementation. NAVAIR developed devices (non-COTS) are still under development at the time of this writing and not available for immediate implementation. Immediate implementations will consist of only COTS devices as they are readily available. Long-term implementation recommendations may be any mix of non-COTS and COTS solutions.

IV. RESULTS

Using the methodology developed in Chapter III, this chapter discusses the results found by the team. This includes all identified measurements, identified devices, and the evaluation of devices which were defined.

A. MEASUREMENTS

The team identified 11 measurements that encompass the cockpit environment and aircrew physiological state. Seven of these are human measurements concerned with aircrew and true biometric monitoring. The remaining four are environmentally-based for understanding the cockpit environment during PE incidents. The measurements were given importance ratings as to how they could help determine or reconstruct a PE incident by the NAVAIR SME. A rating of 1 indicates little importance whereas a rating of 5 indicates high importance. This rating was utilized in the sensor suite development within the multiple configuration evaluation.

1. Human Measurements

Table 6 lists the seven human measurements concerned with the aircrew and associated reason for addressing the measurement. No ranking was provided for oxygen intake and output due to lack of identified devices capable of capturing these measurements. The team discovered some devices that could monitor oxygen levels; however, these devices could not be integrated with the current aircrew helmet and oxygen mask. The rankings shown in Table 6 were provided by NAVAIR SME.

Table 6. Human Measurements for Monitoring

Human Measurement	Measurement Rating	Reasoning for Measurement
Heart Rate	5	Heart rate is a biometric measurement that can indicate when an individual's body is undergoing stressing conditions such as PE. Heart rate is a measurement that is already being collected by the Navy for all flights.
Core Temperature	2	Heat stress and heat strain can have adverse effects on aircrew; monitoring core temperature can foresee this condition and allow for preventative actions.
Oxygen Intake		Knowing the percentage of oxygen entering the mask will ensure that the individual is getting enough oxygen to breathe.
Oxygen Output		The percentage of oxygen exiting the mask
Carbon Dioxide Output	4	Knowing the percentage of carbon dioxide exiting the mask will ensure that the aircrew is breathing normally (converting oxygen to carbon dioxide).
Breathing Rate	5	Continuously monitoring the individual breathing rate will show fluctuations in the aircrew breathing pattern when a PE is occurring.
Blood Oxygen Level	5	Monitoring the blood oxygen level gives a clear indication that oxygen is entering the body ruling out other harmful gases.

2. Environmental Measurements

Table 7 lists the four environmental measurements the team used to understand the cockpit environment during PE incidents and associated reason for addressing the measurement. The SME provided an importance rating for these measurements as well.

Table 7. Measurements for the Cockpit Environment

Environmental Measurement	Measurement Rating	Reasoning for Measurement
Tri-Axial G-forces	5	Monitoring the tri-axial G-forces can indicate if a force condition is correlated to the triggering of a PE.
Humidity	1	Fluctuation in humidity can be correlated to the triggering of a PE; knowing the humidity limitations could allow for better PE monitoring.
Air Temperature	2	Temperature of the cockpit directly effects the temperature of the aircrew; therefore, it must be measured to indicate the limits before a PE is triggered.
Air Quality	2	Air quality of the cockpit can give quantitative values on the various percentages of gases present in the cockpit.

B. IDENTIFIED DEVICES

Extensive research led to the below list of proposed solutions currently available on the COTS market or currently under development by NAVAIR. Figure 6 is a top-level list of all identified devices, the measurements they collect, cost, and characteristics. Devices identified in blue are currently being utilized by the Navy, devices identified in green are COTS solutions and devices identified in orange are NAVAIR developed solutions. The red cells in the cost column are costs that are not yet available. The red values in the characteristics are assumed or derived values. Table 8 details the name and a description of the devices. See Appendix B for a full write up on each of the devices.

Device	HUMAN MEASUREMENTS	Heart Rate	Body Temperature	Oxygen Intake	Oxygen Output	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	ENVIRONMENTAL MEASUREMENTS	Temperature	Humidity	Air Quality/Composition	G Force	COST	Cost ($USD)	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body
Fenix 3/5		Y													$ 450		2.9	50	Sports	Lower Limb/Wrist
Slamstick													Y		$ 3,250		2.29	22	Aviation	No Contact
Fly Sentinel		Y						Y		Y	Y	Y	Y		$ 878		4.23	10	Aviation	Lower Limb/Wrist
AtomTube										Y	Y	Y			$ 189		1.34	168	Sports	No Contact
HexoSkin Smart Kit		Y					Y						Y		$ 499		4.9	12	Sports	Body Core
GaugeWear			Y														9.1	10	Sports	Body Core
VivoSmart 4		Y						Y							$ 130		0.6	168	Sports	Lower Limb/Wrist
Drop D2										Y	Y				$ 99		1.2	240	Sports	No Contact
RKI Instruments 72-0341RKC												Y			$ 595		4.6	20	Industrial	No Contact
Equivital Wearable ECG		Y	Y				Y	Y					Y		$ 10,000		1.34	12	Sports	Body Core
TrackAid Pulse Monitor		Y						Y							$ 15		1.6	30	Healtcare - Dynamic	Hands
Garmin Chest Strap		Y													$ 130		2.08	300	Sports	Body Core
AWARE		Y	Y														1.1	10	Aviation	Body Core
MICROS		Y	Y														1.12	10	Aviation	Body Core
HMAPS		Y	Y					Y					Y				9.1	10	Aviation	Body Core
SPYDR		Y						Y					Y				2.46	10	Aviation	Head
MASES						Y											0.7	10	Aviation	Head
SONITUS						Y											0.6	10	Aviation	Head
Pocket NIRS								Y									3.5	10	Aviation	Upper Limb

Figure 6. Identified Devices – Abbreviated

Table 8. Identified Devices – Complete

Device	Description	Summary
 Fenix 3/5 (Garmin, Garmin Fenix 3 2019)	Currently used by F/A-18 aircrew. The Fenix3/5 is implemented for aviators to have a visual, audible, and proprioceptive alert to identifying an issue in the cockpit. There is a NAVAIR app, available from the Garmin store, which provides features tailored specific to the pilot. Its current measurement is heart rate (Garmin, Garmin Fenix 3 2019).	Cost: $450 Measurements: heart rate Weight (oz.): 2.9 Battery Life (hrs.): 50 Location: Wrist Design Intent: Sports
 SlamStick (Midé Technology Corporation 2019)	Currently used by F/A-18 aircrew. SlamStick is a device used to measure pressure changes with time, rate, and amplitude. The SlamStick is not a real-time warning device; the device collects data for post-flight evaluation (Joyner 2018).The SlamStick measures temperature, pressure, cabin altitude, and report these in 1Hz increments. Data is downloaded with a maintenance card data and analyzed for pressurization fluctuations (Midé Technology Corporation 2019).	Cost: $2,000 Measurements: G-Force Weight (oz.):2.29 Battery Life (hrs.):22 Location: Wrist Design Intent: Aviation
 Fly Sentinel (FlySentinel 2018)	Battery operated watch device designed for operation in a cockpit that measures aircrew's physiological parameters: heart rate, oxygen saturation, and blood pressure, their surrounding environment: temperature, humidity, noise level, G-force, CO and carbon dioxide level, and their Global Positioning System (GPS) coordinates and altitude. If safety concerns are detected, the device will provide a visual and proprioceptive alert to the aircrew that will suggest corrective actions if possible. In the case of an emergency, the device will send out a GPS distress call with the aircrew's GPS location and summary of emergency. Data provided from this device uploads to the Sentinel Cloud Service or a PC in reference to analysis and graphical interpretation (FlySentinel 2018).	Cost: $877 Measurements (Person): blood oxygen saturation, heart rate Measurements (Environmental): Temperature, humidity, CO, noise, altitude, G-force Weight (oz.):4.23 Battery Life (hrs.):10 Location: Wrist Design Intent: Aviation

Table 8. Identified Devices – Complete (cont.)

Device	Description	Summary
 Atom tube/Atomtube Pro (Atomtube 2015).	The Atomtube/Atomtube pro is a small, portable device that provides continuous monitoring of environmental conditions such as air quality (volatile organic compounds), temperature, humidity, atmospheric pressure, altitude. Device is not required to be directly attached to the pilot and can be mounted/stored in the cockpit. If environmental conditions show dangerous conditions, an alert will be sent via Bluetooth to a mobile device via the Atomtube application (Atomtube 2015).	Cost: $99-189 Measurements: PM1,2.5,10 particle detector, harmful gases and VOC sensor, barometer/altimeter, temperature, humidity Weight (oz.):1.34 Battery Life (hrs.):168 Location: No Contact Design Intent: Sports
 VivoSmart 4 (Garmin, Garmin Vivosmart 4: Fitness Activity Tracker: Pulse Ox 1996).	The Garmin watch, VivoSmart 4, that can gauge blood oxygen saturation levels (built in pulse oximeter), heart rate, stress tracking, relaxation breathing timer, and location via GPS tracker. Device provides alerts via application notification on a mobile device or computer utilizing Bluetooth (Garmin, Garmin Vivosmart 4: Fitness Activity Tracker: Pulse Ox 1996).	Cost: $130 Measurements: heart rate, stress tracking, blood oxygen saturation Weight (oz.): .6 Battery Life (hrs.): 168 Location: Wrist Design Intent: Sports
 Hexoskin Smart Kit (Carre Technologies Inc. 2019).	The Hexoskin Smart Kit includes the Hexoskin smart shirt and smart device shown in the image. This together provides the user to with cardiac and respiratory monitoring data that can be available instantaneously or uploaded to a device to be analyzed later via Bluetooth to a mobile device or computer with their app. The smart shirt will be able to be worn underneath the user's uniform (Carre Technologies Inc. 2019).	Cost: $499 Measurements: heart rate, heart rate variability (HRV) and heart rate recovery (HR2), Breathing rate and volume, 3-axis accelerometer, Step count, cadence, stride, Activity level and calories burned Weight (oz.): 4.9 Battery Life (hrs.): 12 Location: Shirt Design Intent: Sports

Table 8. Identified Devices – Complete (cont.)

Device	Description	Summary
 RKI Instrument (Transcat Inc. 2018).	The RKI Instrument shown above weighs about 4.6 ounces and can fit in the palm of your hand. It monitors and displays combustibles, oxygen, carbon monoxide, and hydrogen sulfide. The device provides visual and proprioceptive alerts to alert the aircrew if any gasses are observed in the cockpit (Transcat Inc. 2018).	Cost: $595 Measurements: lower explosive limit (LEL), oxygen, hydrogen sulfide (H2S), CO Measurement Weight (oz.): 4.6 Battery Life (hrs.): 20 Location: No Contac Design Intent: Industrial
 Kestrel Drop D2 (Nielsen-Kellerman Co. 2019).	The Drop D2 device is a small device that measures temperature, pressure, relative humidity, and density altitude. Data is transmitted via Bluetooth to an app capable of storing months of data (Nielsen-Kellerman Co. 2019).	Cost: $99 Measurements: Temperature, Humidity, Heat Index, and Dew Point Weight (oz.): 1.2 Battery Life (hrs.): 240 Location: Keychain Design Intent: Sports
 Equivital (Equivital 2019).	The Equivital Wearable ECG Starter Pack comes with a non-intrusive wireless ECG sensor belt that houses the sensor electronics module (SEM) for physiological monitoring of the measurements (ECG, heart rate, expansion derived Breathing Rate, Skin Temperature and 3-axis accelerometer. Potential for: Core Temperature (Dermal Temperature Patch), Galvanic Skin Response (Response Sensor), SpO-2 and pulse rate (Wireless Pulse Oximetry Sensor)). This device, if out of range of a device that carries its data analysis program, will provide continuous logging of data until aircrew touches ground. The physiological monitoring takes the data from one subject at a time directly into its data analysis program, LabChart, sold separately (Equivital 2019).	Cost: ~$10,000 Measurements: ECG, heart rate, expansion derived Breathing Rate, Skin Temperature and 3-axis accelerometer. Potential for: Core Temperature (Dermal Temperature Patch), Galvanic Skin Response (Response Sensor), SpO-2 and pulse rate (Wireless Pulse Oximetry Sensor) Weight (oz.): 1.34 Battery Life (hrs.): 12 Location: Chest Design Intent: Sports

Table 8. Identified Devices – Complete (cont.)

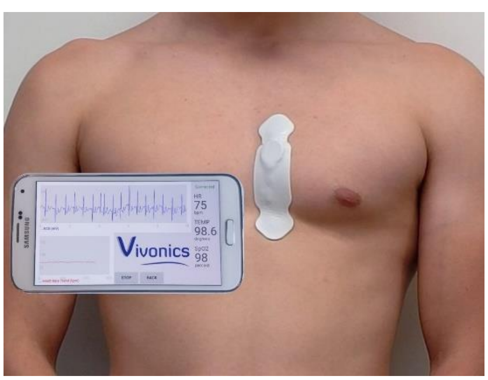
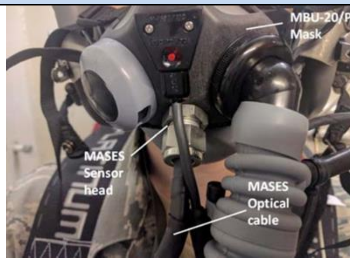
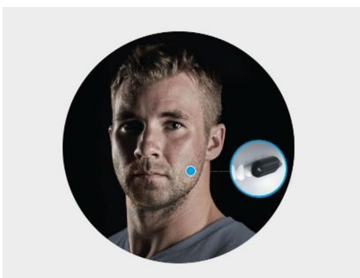
Device	Description	Summary
 TrackAid (TrackAid 1996).	TrackAid is a pulse oximeter device that reads your oxygen saturation level and pulse rate. The device reports the data via a visual LED screen (TrackAid 1996).	Cost: $18.89 Measurements: oxygen saturation level, pulse rate, and pulse strength Weight (oz.): 1.6 Battery Life (hrs.): 30 Location: Fingertip Design Intent: Healthcare - Dynamic
 HRM-Tri (Amazon 1996).	Garmin HRM-Tri is a device that attaches to its user's lower chest to provide HRM. It is capable of storing data as well as sending real time data to a paired device via Bluetooth (Amazon 1996).	Cost: $95.98 Measurements: heart rate Weight (oz.): 2.08 Battery Life (hrs.): 300 Location: Chest Design Intent: Sports
 Active Wearable for Assessment and Remote Evaluation (AWARE) (Vivonics Inc. 2015-2020).	Single use- single patch to collect and transmit physiological data. It is easy to operate with minimum training (Vivonics Inc. 2015-2020).	Cost: $ N/A Measurements: ECG, heart rate, skin temperature, SpO-2 Weight (oz.): ~1.1 Battery Life (hrs.): N/A Location: Chest Design Intent: Aviation

Table 8. Identified Devices – Complete (cont.)

Device	Description	Summary
 Miniature Integrated Circuits Reporting Overall Status (MICROS) (Vivonics Inc. 2015-2020).	Vivonics wearable physiological sensor monitors a wide variety of physiological signals from a single data stream that can be easily mounted on the user's skin (Vivonics Inc. 2015-2020).	Cost: $ N/A Measurements: ECG, EEG, and EMG Weight (oz.): ~ 1.12 Battery Life (hrs.): N/A Location: Chest Design Intent: Aviation
 HMAPS Monitoring System (Athena GTX Inc. 2019)	HMAPS is a joint effort between NAWCADPAX and Athena GTX to take a commercial variant of a wearable sensor suite and modify it to leverage the ongoing USN platform with new technology that will detect, predict, and warn of decreased operator functions before an injury can occur (Shender and Wathen 2019).	Cost: $N/A Measurements: ECG, SpO-2, skin temperature, pulse rate, heart rate Weight (oz.): ~9.1 Battery Life (hrs.): 10 Location: Chest Design Intent: Aviation
 SPYDR (Spotlight Labs 2019)	PMA-202 has been working to integrate the SPYDR ear cup into any helmet for any aircraft as advertised for the Navy. It has been tested by USAF in the centrifuge, altitude chamber, and RBD and has flown over 100 sorties in F-16, T-6, and T-38 (Shender and Wathen 2019).	Cost: $10,000 per helmet retrofit Measurements: Pulse Rate, peripheral capillary oxygen saturation (SpO2), Cabin Pressure, Acceleration, Hypoxia Alert Weight (oz.): 2.46 Battery Life (hrs.): 10 Location: Ear Design Intent: Aviation

Table 8. Identified Devices – Complete (cont.)

Device	Description	Summary
 MASES (Delgado Alonso, Berry, and Guzman 2018)	PMA-202 has been working to integrate this technology to the aircrew's mask. It will require the mask to be retested and evaluated once the modification has been implemented (Shender and Wathen 2019).	Cost: N/A Measurements: In-mask ppCO2 Weight (oz.): ~.7 Battery Life (hrs.): N/A Location: Underneath Mask Design Intent: Aviation
 Sonitus Intra-Oral Sensor Platform (Sonitus 2019)	PMA-202 has been working to integrate this technology to the Naval fleet. As it is currently only available to measure as a molar mic, work is being completed to create a variant of this technology to measure Pulse Ox, Temperature, accelerometer, ECG, carbon dioxide/VOC with an alert mechanism. It is still under the testing and evaluation phase (Shender and Wathen 2019).	Cost: N/A Measurements: In-mask ppCO2 Weight (oz.): ~.6 Battery Life (hrs.): N/A Location: Oral Design Intent: Aviation
 Pocket NIRS – Portable Near-Infrared Tissue Oxygenation Monitor System (DynaSense Inc. n.d.)	Small lightweight monitoring device that will attach to the exterior skin of its user to measure the change of the oxygenation concentration within a biological tissue in a non-intrusive manner (DynaSense Inc. n.d.).	Cost: N/A Measurements: SpO2 Weight (oz.): 3.5 Battery Life (hrs.): 6 Location: Wrist and Arm Design Intent: Aviation

C. GO/NO-GO EVALUATION

The COTS devices were subjected to a go/no-go evaluation defined in Chapter III. It is important to note that the NAVAIR developed devices were assumed to have passed the go/no-go evaluation as they are being developed specifically for this use by the Navy. Figure 7 shows the 12 devices and the results from the go/no-go evaluation.

Figure 7 shows that all but one identified device passed the three requirements set for the go/no-go evaluation. The TrackAid Pulse Monitor interferes with the gear that the aircrew uses because its placement is over the finger, preventing the individual from performing mission essential tasks.

	Go/No-Go Evaluation	Measure desired measurement	Doesn't interfere with gear	Minimum 10hr battery life	Final outcome
Fenix 3/5 *		Pass	Pass	Pass	Pass
Slamstick *		Pass	Pass	Pass	Pass
Fly Sentinel		Pass	Pass	Pass	Pass
AtomTube		Pass	Pass	Pass	Pass
HexoSkin Smart Kit		Pass	Pass	Pass	Pass
GaugeWear		Pass	Pass	Pass	Pass
VivoSmart 4		Pass	Pass	Pass	Pass
Drop D2		Pass	Pass	Pass	Pass
RKI Instruments 72-0341RKC		Pass	Pass	Pass	Pass
Equivital Wearable ECG		Pass	Pass	Pass	Pass
TrackAid Pulse Monitor		Pass	Fail	Pass	Fail
Garmin Chest Strap		Pass	Pass	Pass	Pass

Figure 7. Device Selection Results

D. SAFETY SURVEY EVALUATION

The safety survey was conducted via a statistical survey tool, called LimeSurvey (Schmitz n.d.). The devices were identified in the survey tool and evaluated by aircrew. The questions that were asked in the survey were:

- Question 1: Will (proposed solution) interfere with crew operations within the aircraft?
- Question 2: Will (proposed solution) interfere with egress in the case of an emergency?

It is important to note that the NAVAIR developed devices were exempted from the safety survey as they are being developed specifically for this use by the Navy. Figure 8 shows the results from the safety survey, IRB approval number NPS.2019.0074-AM01-EM2-A.

	OPERATIONAL INTERFERENCE	1	2	3	4	EGRESS INTERFERENCE	1	2	3	4	FINAL RESULT	Final Result
Fenix 3/5		3	2				5					Pass
Slamstick		4					5					Pass
Fly Sentinel		4	1				2	2				Pass
AtomTube		1	4				2	3				Pass
HexoSkin Smart Kit		4	1				4	1				Pass
GaugeWear		1	4				3	2				Pass
VivoSmart 4		5					5					Pass
Drop D2		4		1			2	2	1			Fail
RKI Instruments 72-0341RKC		3	2				2	3				Pass
Equivital Wearable ECG			4	1			1	4				Fail
TrackAid Pulse Monitor												Fail
Garmin Chest Strap		4	1				5					Pass

Figure 8. Aircrew Safety Evaluation Results

The results show the total responses for each potential response on all non-NAVAIR developed solutions that passed the go/no-go requirements. Per the grading requirements defined in Chapter III, a grade of 1 is no inference and 4 significant inference. Any solution with an answer of 3 or 4 was considered an unacceptable safety risk and removed from consideration. Any failing responses are highlighted in red in Figure 8. The table shows the Equivital Wearable ECG and the DropD2 as unacceptable identified devices. TrackAid was not given as a survey option because it failed the go/no-go requirement to not interfere with the uniform, PPE, or flight gear.

E. CHARACTERISTIC EVALUATION

The devices that passed the go/no-go requirements and the aircrew safety evaluation were then evaluated via the characteristic evaluation detailed in Chapter III. Figure 9 shows the results of the characteristic evaluations for each device and each measurement. Appendix C shows the details of each rating broken down by measurement.

	CHARACTERISTIC EVALUATION	Heart Rate	Body Temperature	Oxygen Intake	Oxygen Output	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	Temperature	Humidity	Air Quality/Composition	G Force
Fenix 3/5		63	-	-	-	-	-	-	-	-	-	-
Slamstick		-	-	-	-	-	-	-	-	-	-	92
Fly Sentinel		60	-	-	-	-	-	60	63	63	63	66
AtomTube		-	-	-	-	-	-	-	90	90	90	-
HexoSkin Smart Kit		65	-	-	-	-	79	-	-	-	-	71
GaugeWear		-	65	-	-	-	-	-	-	-	-	-
VivoSmart 4		75	-	-	-	-	-	75	-	-	-	-
Drop D2		-	-	-	-	-	-	-	-	-	-	-
RKI Instruments 72-0341RKC		-	-	-	-	-	-	-	-	-	70	-
Equivital Wearable ECG		-	-	-	-	-	-	-	-	-	-	-
TrackAid Pulse Monitor		-	-	-	-	-	-	-	-	-	-	-
Garmin Chest Strap		79	-	-	-	-	-	-	-	-	-	-
AWARE		81	88	-	-	-	-	-	-	-	-	-
MICROS		81	88	-	-	-	-	-	-	-	-	-
HMAPS		74	75	-	-	-	-	74	-	-	-	77
SPYDR		77	-	-	-	-	-	77	-	-	-	87
MASES		-	-	-	-	86	-	-	-	-	-	-
SONITUS		-	-	-	-	88	-	-	-	-	-	-
Pocket NIRS		-	-	-	-	-	-	68	-	-	-	-

Figure 9. Characteristic Evaluation Results

F. MULTIPLE CONFIGURATION EVALUATION

The multiple configuration evaluation resulted in 243 total unique sensor suites that utilize two, three, or four contact devices. All but 24 sensor suites utilize COTS solutions. There were no single contact device sensor suites. All of the sensor suites include all three of the non-contact devices available. As mentioned, in Chapter III Section I, the sensor suites will be evaluated via several criteria and will be discussed later in this section. The highest values indicate a sensor suite of the top rating and significance and were chosen as possible options. This high score value indicates a higher confidence level in the sensor suite to better capture and foresee the measurements present in a PE. If a measurement is duplicated, that does not make it a negative characteristic but provides a secondary resource of that data. All possible sensor suite options are listed in Appendix D. Multiple Configuration MATLAB OUTPUT.

Source code used to generate all possible combination options is available as a supplement, see Supplemental 2. MATLAB Code

for additional information. The breakdown of the sensor suites' data is detailed in Figure 10. It is important to note that the COTS and non-COTS Only data are subsets of the 2, 3, and 4 device configurations. Additionally, the number of devices does not include the no contact devices. The term "option" is listing in Figure 11 in order to cross-reference the MATLAB code that was used to capture these values.

	Total Options	Min Value	Max Value
4 Contact Alternatives	54	1688	2403
3 Contact Alternatives	108	1266	2403
2 Contact Alternatives	81	922	2321
COTS Only	18	1645	2051
Non-Cots Only	24	922	1626

Figure 10. Multiple Configuration Breakdown

The rating for all 243 options is shown in Figure 11. The indicated values are the ratings that the combinations received. The min and max values are based on all sensor suites with the same number of devices. The rating is the total sum product of the characteristic rating for every measurement captured and the associated weight of each measurement. The highest performers for each category, noted in the red box, are detailed further. The results of the analysis of these suites are detailed in Chapter V.

Figure 11. Sensor Suit Options 1 – 243

For the four device options, the highest performers are options #4 through #9. The top performers for the three device options are options #85 through #90, and options #137 and #138. The top performers of the two device sensor suites are options #203 and #204. Any device that are missing measurements are identified in red. The devices highlighted in light blue are devices currently being used by the Navy; devices that are highlighted in green are COTS solutions, and devices that are highlighted in orange are NAVAIR developed solutions. The total scores are listed on the left of the figures adjacent to the option number.

The top performers of the four-device configuration device solutions are detailed in Figure 12. All options are missing body temperature; however, body temperature is designated with low measurement rating in Table 6. If a COTS device were to be used to capture body temperature, then it would duplicate the location of a device with a higher rated measurement.

Option	Cost	Device	HUMAN MEASUREMENTS	Heart Rate	Body Temperature	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	ENVIRONMENTAL MEASUREMENTS	Temperature	Humidity	Air Quality/Composition	G Force	PHYSICAL CHARACTERISTICS	Locations on Body
				5	2	4	5	5		2	1	2	5		0.3
Option #4	2312.5	Fenix 3/5		Y											Lower Limb/Wrist
		Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		MASES				Y									Head
		Pocket NIRS						Y							Upper Limb
Option #5	2312.5	Slamstick											Y		No Contact
		Fly Sentinel		Y				Y		Y	Y	Y	Y		Lower Limb/Wrist
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		MASES				Y									Head
		Pocket NIRS						Y							Upper Limb
Option #6	2395	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		VivoSmart 4		Y				Y							Lower Limb/Wrist
		RKI Instruments 72-0341RKC										Y			No Contact
		MASES				Y									Head
		Pocket NIRS						Y							Upper Limb
Option #7	2320.5	Fenix 3/5		Y											Lower Limb/Wrist
		Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		SONITUS				Y									Head
		Pocket NIRS						Y							Upper Limb
Option #8	2320.5	Slamstick											Y		No Contact
		Fly Sentinel		Y				Y		Y	Y	Y	Y		Lower Limb/Wrist
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		SONITUS				Y									Head
		Pocket NIRS						Y							Upper Limb
Option #9	2403	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		VivoSmart 4		Y				Y							Lower Limb/Wrist
		RKI Instruments 72-0341RKC										Y			No Contact
		SONITUS				Y									Head
		Pocket NIRS						Y							Upper Limb

Figure 12. Four-Contact Device Sensor Suites

Based on Figure 12, option 9 is the best sensor suite with the four-device configuration. It received the highest score from the analysis with a score of 2403. The table shows that it captures all the data that is required except for body temperature. Option 9 also has redundant data capture of the heart rate, blood oxygen level and G force. This is important because these are important measurements that predict PE. This can attribute to its high sensor suite rating.

The top performers of the three-device solutions are detailed in Figure 13. All options are missing body temperature, which is a low-rated measurement. Two options of the three-device solutions are missing blood oxygen level, which is a high-rated measurement. There are six options that capture all measurements except body temperature. Option 90 is the highest rated suite in this group. This option has redundant measurements as well as collecting measurements of high importance like G force and heart rate.

			HUMAN MEASUREMENTS					ENVIRONMENTAL MEASUREMENTS				PHYSICAL CHARACTERISTICS
			Heart Rate	Body Temperature	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	Temperature	Humidity	Air Quality/Composition	G Force	Locations on Body
			5	2	4	5	5	2	1	2	5	0.3
Option # 85	2312.5	Fenix 3/5	Y									Lower Limb/Wrist
		Slamstick									Y	No Contact
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		RKI Instruments 72-0341RKC								Y		No Contact
		MASES			Y							Head
Option # 86	2395	Slamstick									Y	No Contact
		Fly Sentinel	Y				Y	Y	Y	Y	Y	Lower Limb/Wrist
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		RKI Instruments 72-0341RKC								Y		No Contact
		MASES			Y							Head
Option # 87	2320	Slamstick									Y	No Contact
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		VivoSmart 4	Y				Y					Lower Limb/Wrist
		RKI Instruments 72-0341RKC								Y		No Contact
		MASES			Y							Head
Option # 88	2320	Fenix 3/5	Y									Lower Limb/Wrist
		Slamstick *									Y	No Contact
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		RKI Instruments 72-0341RKC								Y		No Contact
		SONITUS			Y							Head
Option # 89	2320.5	Slamstick *									Y	No Contact
		Fly Sentinel	Y				Y	Y	Y	Y	Y	Lower Limb/Wrist
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		RKI Instruments 72-0341RKC								Y		No Contact
		SONITUS			Y							Head
Option # 90	2403	Slamstick									Y	No Contact
		AtomTube						Y	Y	Y		No Contact
		HexoSkin Smart Kit	Y			Y					Y	Body Core
		VivoSmart 4	Y				Y					Lower Limb/Wrist
		RKI Instruments 72-0341RKC								Y		No Contact
		SONITUS			Y							Head

Figure 13. Three-Device Sensor Suites (part 1 of 2)

Option	Score	Device	HUMAN MEASUREMENTS	Heart Rate	Body Temperature	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	ENVIRONMENTAL MEASUREMENTS	Temperature	Humidity	Air Quality/Composition	G Force	PHYSICAL CHARACTERISTICS	Locations on Body
				5	2	4	5	5		2	1	2	5		0.3
Option# 137	2312.5	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		MASES				Y									Head
		Pocket NIRS						Y							Upper Limb
Option# 138	2320.5	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		SONITUS				Y									Head
		Pocket NIRS						Y							Upper Limb

Figure 13. Three-Device Sensor Suites (part 2 of 2)

The top performers of the two-device solutions are detailed in Figure 14. Both options of the two-device solutions are missing blood oxygen level, which is a high-rated measurement. Of these sensor suites, neither measures blood oxygen level, a top-rated measurement per the NAVAIR SME. The data in figure shows that two-device sensor suites are not a good option as they miss important measurements that are captured in the three-and four-device options.

			HUMAN MEASUREMENTS	Heart Rate	Body Temperature	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	ENVIRONMENTAL MEASUREMENTS	Temperature	Humidity	Air Quality/Composition	G Force	PHYSICAL CHARACTERISTICS	Locations on Body
				5	2	4	5	5		2	1	2	5		0.3
Option # 203	2313.5	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		MASES				Y									Head
Option # 204	2320.5	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
		SONITUS				Y									Head

Figure 14. Two-Device Sensor Suites

The sensor suites that only utilize COTS devices were assessed individually. The team recommends COTS-only sensor suites for implementation for immediate use while the NAVAIR specific devices are in development. The top performers of the COTS only suites are detailed in Figure 15. All options are missing body temperature and carbon dioxide output. There are no COTS devices identified by the team that are capable of measuring carbon dioxide output. While there are COTS devices capable of measuring body temperature, it is a lower importance rated measurement, at a rating of 2 out of 5, and cannot be captured without duplicating a location on the wearer or sacrificing a higher importance measurement.

Option		Sensor	HUMAN MEASUREMENTS	Heart Rate	Body Temperature	Carbon Dioxide Output	Breathing Rate	Blood Oxygen Level	ENVIRONMENTAL MEASUREMENTS	Temperature	Humidity	Air Quality/Composition	G Force	PHYSICAL CHARACTERISTICS	Locations on Body
				5	2	4	5	5		2	1	2	5		0.3
Option # 175	1968.5	Fenix 3/5		Y											Lower Limb/Wrist
		Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
Option # 176	1968.5	Slamstick											Y		No Contact
		Fly Sentinel		Y				Y		Y	Y	Y	Y		Lower Limb/Wrist
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		RKI Instruments 72-0341RKC										Y			No Contact
Option # 177	2051	Slamstick											Y		No Contact
		AtomTube								Y	Y	Y			No Contact
		HexoSkin Smart Kit		Y			Y						Y		Body Core
		VivoSmart 4		Y				Y							Lower Limb/Wrist
		RKI Instruments 72-0341RKC										Y			No Contact

Figure 15. COTS-Only Sensor Suites

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In the discussion of identifying PE and HL-PE during flight for the naval fleet, the team recommends COTS solutions as a short-term implementation and a combination of COTS and non-COTS solutions for long-term implementation. Using the AOA process, go/no-go evaluation and aircrew survey, the team produced a list of applicable and wearable combinations of COTS devices. The team identified a total of 19 commercial solutions which were compiled in a matrix and evaluated.

The biometric measurements that were selected by the team have been chosen because of the symptoms aircrew have seen in previous flights and investigations. The selected measurements will be able to reconstruct flight data and provide insight into PE episodes. There are 11 measurements that cover the cockpit environment and aircrew physiological state. Seven of these measurements are human measurements: heart rate, core temperature, oxygen intake, oxygen output, carbon dioxide output, breathing rate, and blood oxygen level. The last four measurements are environmental measurements: tri-axial G-forces, humidity, air temperature, and air quality.

The go/no-go requirements and aircrew survey evaluation were developed to ensure aircraft safety, device operation for the duration of a flight, if the device will affect flight operations, and if the device will affect egress. If the device did not meet all the go/no-go requirements it was removed from evaluation. The only device that did not pass the go/no-go requirement was the TrackAid Pulse Monitor because it interfered with the aircrew's gear. All devices that met the go/no-go criteria and were not being developed by NAVAIR were subject to an aircrew survey evaluation. The Drop D2 was eliminated due to aircrew stating it would interfere with flight operations and egress. The Equivital Wearable ECG was also eliminated due to aircrew stating it would interfere with flight operations.

After all the devices had been evaluated individually for their performance, the sensor suites were developed via the MATLAB code discussed in Chapter III Section I. The program provided a comprehensive list of all two, three, and four contact-based device combinations using a mixture of COTS and non-COTS, COTS-only devices, and non-COTS only devices along with their corresponding sensor suite rating. Measurement duplication was considered a positive as it provided redundancy in the measurements and a secondary source of data for data validation. The goal of the sensor suites is to provide the best choices that cover the most measurements, but with the fewest number of devices. The top performers of the sensor suites were then subjected to a qualitative evaluation based on data redundancy, any available cost data, importance of the measurements captured, and device availability.

B. RECOMMENDATIONS

As previously discussed, there are two groups of recommendations: short and long term. Short-term implementation recommendations are limited to COTS solutions only. NAVAIR developed devices are still under development and therefore not ready for implementation. Long-term implementations are mixed sensor suites containing COTS and non-COTS solutions.

Since the technical scores are very similar, the team considers the following criteria to be applicable to use in narrowing down to a final set of recommendations:

1. Importance of included measurements
2. Number of included measurements and redundant measurements
3. Number of devices

The limited cost data available and the relative cost of the COTS products compared to overall aircrafts costs indicates that difference in cost is not an important consideration.

1. Short-Term Implementation

For the immediate implementation, Figure 15 details the top performers of the COTS only solutions. Option #175 is missing blood oxygen levels, a top-rated measurement, and therefore is removed from consideration. Options #176 and #177 are recommended for immediate implementation. The only difference between the two combination options is the wrist wearable device. The Fly Sentinel is more expensive, but provides more measurements, this data redundancy is useful for data validation and ensures all measurements it collects are time synced. The VivoSmart 4 watch is from Garmin, which already has existing NAVAIR specific application used in the Fenix watch.

2. Long-Term Implementation

The two-, three- and four-device options all provided solutions that score comparatively similarly. The cockpit environment is a stressful and dynamic environment for all operators. The preference is to utilize the fewest contact-based devices possible in order to mitigate user performance error due to limited mobility and fatigue due to weight.

Option #203 and #204 of the 2-device solutions are missing blood oxygen level. The preference is to use the least devices possible, but not at the expense of vital data collection. For this reason, the two-device solutions are removed from consideration for long term implementation.

Option #85 and #88 of the three-device solutions are also missing blood oxygen level, and therefore removed from consideration. For the remaining options, both three- and four-device solutions, the addition of a fourth device does not provide any additional benefit in regards to data collection. With the goal to minimize the amount of devices on the user while maximizing the data collected, the following three-device solutions are recommended for long term implementation: #86 and #89. Several of the three-device solutions have comparable performance numbers but the two recommended provide the most important measurements and the most data redundancy. Both options have multiple data redundancy with: heart rate, outside temperature, humidity, air quality, and G-force. The main difference between these solutions is the NAVAIR developed device used. Both use the FlySentinel, which provides an abundance of data redundancy. The sensor suites that include NAVAIR developed devices used will be limited by availability and development completion.

3. Testing Recommendations

After these devices are considered the team recommends more detailed testing. The devices need be tested in an aviation environment to validate the pressure effects on accuracy of COTS devices before sensors are deployed (Phillips, Warner, and Geyer 2016). The devices also need to be tested in the aviation environment to ensure that they meet all safety and performance parameters. During these tests, the effects of shock and vibrations need to be analyzed in order to ensure that the devices will have a high rate of survival. It is also recommended that any technique intended to be implemented for physiological monitoring must first pass the safe-to-fly EMI testing to ensure it does not pose a threat to the mission capability of tactical aviation (Phillips, Warner, and Geyer 2016).

C. FUTURE WORK

Due to a limited amount of information on the products in development from NAVAIR and uncertainty of suitability of COTS devices for the aviation environment, a lot of work remains to ascertain the actual comparative value of the sensor suites that the team recommended. The path forward for this project would be to address the constraints of this project and to address the requirements that were out of scope.

One constraint that the team listed was the limited data on cost of these devices. If any organization were to use the recommendation from the team, the cost of the devices would have to be evaluated to see if the cost is feasible for purchasing for the fleet. They will also need to research the life cycle cost, like the operational cost, the maintenance (renewal and maintain) cost, and the end of life costs.

Before purchasing, however, it would be pertinent to test the recommended COTS devices to ensure that they work in aviation settings, which has different environmental conditions and were previously discussed in Table 4. The team could not perform tests on due to time and constraints during this project. Evaluation of these requirements, as listed below, would ensure a better-quality product being produced for the fleet. Before product integration, its recommended to conduct the evaluations discussed.

(1) Operational Feasibility in Dynamic Flight Environment

Evaluating the ability of a device to operate under dynamic flight environment such as varying barometric pressure, altitude, or G-forces. would ensure product reliability in aviation settings. COTS devices are not necessarily tested in aviation settings, so testing would confirm product suitability.

(2) Operational Compatibility

Evaluating the requirement to have a product that is operationally compatible, ability to meet the criteria of different platforms, would ensure the product can be used in various aircraft settings.

(3) Shock and Vibration

Evaluating the requirement to attempt to mitigate the effects of shock and vibration would ensure that the device works in an aviation environment.

(4) Security Risk or Violation

Evaluating the security risk of each device would ensure that the product cannot be compromised to distribute information or rendered to be unusable.

(5) Interference with Avionics and Weapons System (Electro-magnetic Interference)

Evaluating the interference with avionics and weapons systems requirement would ensure that the devices are operable in aviation settings.

(6) Wireless Data Transmission

Evaluating whether the wireless data transmission requirement would reduce cyber security risk.

(7) Other PPE

Evaluating the product in respect to its placement around other PPE would ensure that the product is producing accurate and reliable data.

Physiological episodes are a problem that continue to negatively impact the military, thus it is imperative that stakeholders investigate devices to mitigate and prevent PEs in the future. As of December 2019, NAVAIR released a request for information (RFI) for fabrics that can be used in biosensing garments for aviation (General Services

Administration 2019). The RFI shows that the future for PE technology is headed in the direction of wearable biosensing garments. This push for advancement in biosensing garment technology would offer devices that aircrew can wear safely without much interference and would ideally capture multiple human measurements. The devices would be ideal for the analysis the team did in this project.

Along with this recommendation to continue advancements in wearable biosensing fabrics, the stakeholders should continue to evaluate the interoperability of the technology. Evaluation of interoperability would ensure that the technology can be used in various types of aircraft since PE are not limited to a single aircraft.

APPENDIX A. DEVICES CHARACTERISTICS ASSUMPTIONS AND EXTRAPOLATIONS

The following lists every device identified and used in the study. Each device has a brief description and parameters listed (identified through research and/or derived). It is important to note how various parameters were derived.

1. Battery life: NAVAIR devices were assumed to meet the minimum battery life requirement of 10 hours. All other devices listed, were researched values for their battery life.

2. Weight: Gaugewear was assumed to have the maximum weight of all the devices as it is a prototype and no real weight value has been identified due to lack of available information. MASES and Sonitus have low derived weight values due to devices still being in test and evaluation stage of the SE process, thus lacking a firm weight value. AWARE and MICROS also have low derived weight values due to the devices being wearable skin sensors that may vary based on size and number of sensors used.

3. AWARE and MICROS are very similar devices. They both are patches that are put on the subject's chests in order to monitor different biometrics. Due to this, the DR400 Holter & Event Patch Recorder was chosen as a comparative tool, because it is similar to both products. It is used to monitor the patient's heart. It is also roughly the same size based on pictures. The DR400 weighed in at 1.05 ounces. This was used as the measuring point for the AWARE and MICROS patches. The AWARE would have to have more sensor's so it was decided that an extra 0.05 ounces was reasonable to add to the patch. This made the weight of the AWARE patch 1.10 ounces. The MICROS was made of heavier material, so a little more weight was determined for it. This gave it a weight of 1.12 ounces.

4. The MASES sensor is a small metallic like sensor that is attached to the base of the mask of the aircrew. The Titan Tools 19442 is an air flow regulator that seems to be similar to the MASES. This a sensor that is used to regulate airflow into other systems. This is similar in size and of heavier materials due to its task. Because of these reasons, it was determined that it was slightly heavier than the MASES sensor. The Titan weighs in at 0.8 ounces. The weight that was determined for the MASES was 0.7 ounces.

5. The HMAPS sensor is a wearable device that is strapped to the arm of the aircrew. The Digital Wrist Blood Pressure Monitor for Health Monitoring is similar in size of the HMAPS monitoring system. The blood pressure monitor has a weight of 8.6 ounces. The HMAPS system has more sensors and is made of heavier material, but with a smaller display screen. With all that factored in, it was determined to add a little more weight to the HMAPS monitoring system, giving it a weight of 9.1 ounces.

6. The Sonitus sensor is an oral device that will attach to the inside of the user's teeth. The SNAPSHOT Intraoral sensor will take images of patient's teeth; it has a weight of 4.2 ounces. The Sonitus is a little smaller and does not have as many sensors as the SNAPSHOT. Both devices are made out of waterproof material. The SNAPSHOT also has a USB cable connected to which weighs about 3.6 ounces, it was determined that the Sonitus weighs slightly less than the SNAPSHOT, which gives it a weight of 0.6 ounces.

7. Human measurements, environmental measurements, design intent, and locations on body values: all values reported were identified through research of each device.

APPENDIX B. IDENTIFIED DEVICES

A. FENIX WATCH

Currently used by F/A-18 aircrew. The Fenix3/5 is implemented for aviators to have a visual, audible, and proprioceptive alert to identifying an issue in the cockpit. There is a NAVAIR app, available from the Garmin store, which provides features tailored specific to the aircrew. Its currently utilized measurement is heart rate. (Garmin, Garmin Fenix 3 2019).

- Manufacturer: Garmin
- Cost: $450
- Measurements (Person): heart rate
- Measurements (Environmental): N/A
- Weight (oz.): 2.9
- Battery Life (hrs.): 50
- Location on Person: Wrist
- Design Intent: Sports

B. SLAMSTICK

Currently used by F/A-18 aircrew. SlamStick is a device used to measure pressure changes with time, rate, and amplitude. The SlamStick is not a real-time warning device; the device collects data for post-flight evaluation (Joyner 2018). The SlamStick measures temperature, pressure, cabin altitude, and report these in 1Hz increments. Data is downloaded with a maintenance card data and analyzed for pressurization fluctuations (Midé Technology Corporation 2019).

- Manufacturer: Mide Technology Corporation
- Cost: $2,000
- Measurements (Person): N/A
- Measurements (Environmental): G-Force
- Weight (oz.): 2.29
- Battery Life (hrs.): 22
- Location on Person: no contact
- Design Intent: Aviation

C. FLY SENTINEL

The FlySentinel is a battery-operated watch device that measure the human and environmental conditions listed below. The watch was designed to be operated in a cockpit environment; however, it appears to have been designed for small crash/commercial aviation, so information will be needed to assess the watch under fighter aircraft operations (FlySentinel 2018).

- Manufacturer: MedicoApps
- Cost: $877 [€793]
- Measurements (Person): Blood oxygen saturation, heart rate
- Measurements (Environmental): Temperature, humidity, CO, noise, altitude, G-force
- Weight (oz.): 4.23
- Battery Life (hrs.): 10
- Location on Person: wrist
- Design Intent: Aviation

D. ATOMTUBE

This device is a small, portable air quality monitor. This device provides continuous monitoring for environmental conditions such as air quality, temperature, and humidity (Atomtube 2015).

- Manufacturer: Atom Tube
- Cost: $99 - $189
- Measurements (Person): N/A
- Measurements (Environmental): PM1,2.5,10 particle detector, harmful gases and VOC sensor, barometer/altimeter, temperature, humidity
- Weight (oz.): 1.34
- Battery Life (hrs.): 168
- Location on Person: no contact
- Design Intent: Sports

E. HEXOSKIN SMART KIT

This kit consists of the Hexoskin smart shirt and smart device. This shirt allows the user to monitor different aspects of their heart performance. This device can monitor the heart rate of the user. The smart device allows user's information to be available instantaneously. The information can then be uploaded to an application to be analyzed later. The smart shirt will be able to be worn underneath the user's uniform (Carre Technologies Inc. 2019).

- Manufacturer: Hexoskin
- Cost: $499
- Measurements (Person): heart rate, HRV and HR2, breathing rate and volume, 3-axis accelerometer, Step count, cadence, stride, Activity level and calories burned
- Measurements (Environmental): N/A
- Weight (oz.): 4.9
- Battery Life (hrs.): 12
- Location on Person: shirt
- Design Intent: Sports

F. VIVOSMART 4

The VIVOSMART 4 is a wearable watch device. The Pulse Ox sensor on Vívosmart 4 estimates your body’s blood oxygen saturation level (Garmin, Garmin Vivosmart 4: Fitness Activity Tracker: Pulse Ox 1996).

- Manufacturer: Garmin
- Cost: $130
- Measurements (Person): heart rate, stress tracking, blood oxygen saturation
- Measurements (Environmental): N/A
- Weight (oz.): .6
- Battery Life (hrs.): 168
- Location on Person: wrist
- Design Intent: Sports

G. DROP D2

The Drop D2 is a small device be attached to the user’s body. The Drop D2 measures temperature and humidity. Data is transmitted via Bluetooth to an app can store large amounts of data. (Nielsen-Kellerman Co. 2019).

- Manufacturer: Kestrel
- Cost: $99
- Measurements (Person): N/A
- Measurements (Environmental): Temperature, Humidity, Heat Index, and Dew Point
- Weight (oz.): 1.2
- Battery Life (hrs.): 240
- Location on Person: keychain
- Design Intent: Sports

H. RKI INSTRUMENTS 72–0314RKC

A small device that can fit in a pocket that identifies LEL, oxygen, H2S, and CO. This device is capable of 20 hours of operation. It will alert the aircrew with a vibrational alarm in the event any of the gasses are identified. It is impact resistant and RFI shielded (Transcat Inc. 2018).

- Manufacturer: RKI
- Cost: $595
- Measurements (Person): N/A
- Measurements (Environmental): LEL, oxygen, H2S, CO Measurement
- Weight (oz.): 4.6
- Battery Life (hrs.): 20
- Location on Person: no contact
- Design Intent: Industrial

I. EQUIVITAL WEARABLE ECG

The Equivital Wearable ECG is a wireless ECG sensor belt that monitors physiological measurements described below. The physiological monitoring takes the data from one subject at a time directly into its data analysis program, LabChart (Program sold separately) (Equivital 2019).

- Manufacturer: Equivital
- Cost: ~$10,000
- Measurements (Person): ECG, Heart Rate, expansion derived Breathing Rate, Skin Temperature and 3-axis accelerometer. Potential for: Core Temperature (Dermal Temperature Patch), Galvanic Skin Response (Response Sensor), SpO2 and pulse rate (Wireless Pulse Oximetry Sensor)
- Measurements (Environmental): N/A
- Weight (oz.): 1.34
- Battery Life (hrs.): 12
- Location on Person: chest
- Design Intent: Sports

J. TRACKAID FINGERTIP PULSE RATE MONITOR TA-50DL

The Trackaid monitor reads the users oxygen saturation level and pulse rate. It goes over the user's fingertip. (TrackAid 1996).

- Manufacturer: TrackAid
- Cost: $18.89
- Measurements (Person): Oxygen saturation level, Pulse rate, and pulse strength
- Measurements (Environmental): N/A
- Weight (oz.): 1.6
- Battery Life (hrs.): 30
- Location on Person: finger tip
- Design Intent: Healthcare – Dynamic

K. GARMIN CHEST STRAP HRM

Garmin HRM-Tri is a small and light HRM. The strap goes around the user's chest in order to monitors their heart rate. The data is stored locally on the device.

- Manufacturer: Garmin
- Cost: $95.98
- Measurements (Person): heart rate
- Measurements (Environmental): N/A
- Weight (oz.): 2.08
- Battery Life (hrs.): 300
- Location on Person: chest
- Design Intent: Sports

L. GAUGEWEAR

A wearable body temperature sensor. It is worn on a strap across the lower chest paired with a band on the wrist. Data is transmitted wireless. The device doesn't seem to be available yet, but further research is required (Gaugewear Inc. n.d.).

- Manufacturer: Gaugewear
- Cost: Not Available
- Measurements (Person): Body Temperature
- Measurements (Environmental): N/A
- Weight (oz.): 9.1
- Battery Life (hrs.): 10
- Location on Person: chest
- Design Intent: Sports

M. AWARE

Single use, single patch to collect and transmit physiological data. It is placed over the user's chest. (Vivonics Inc. 2015-2020).

- Manufacturer: Vivonics
- Cost: Not Available
- Measurements (Person): ECG, Heart Rate, Skin Temperature, SpO2
- Measurements (Environmental): N/A
- Weight (oz.): ~ 1.1
- Battery Life (hrs.): 10
- Location on Person: chest
- Design Intent: Aviation

N. MICROS

Vivonics wearable physiological sensor monitors the measurement described below from a single data stream. This small patch goes over the user's chest.

- Manufacturer: Vivonics
- Cost: Not Available
- Measurements (Person): ECG, EEG, and EMG
- Measurements (Environmental): N/A
- Weight (oz.): 1.12
- Battery Life (hrs.): 10
- Location on Person: chest
- Design Intent: Aviation

O. HMAPS MONITORING SYSTEM

HMAPS is a joint effort between NAWCADPAX and Athena GTX to take a commercial variant of a wearable sensor suite and modify it to leverage the ongoing USN platform. (Shender and Wathen 2019). This device is strapped to the users arm above the elbow in order to monitor the measurements described below. Manufacturer: NAWCADPAX and Athena GTX

- Cost: Not Available
- Measurements (Person): ECG, SpO2, skin temperature, pulse rate, heart rate
- Measurements (Environmental): G-force
- Weight (oz.): 9.1 oz.
- Battery Life (hrs.): 10
- Location on Person: arm
- Design Intent: Aviation

P. SPYDR

PMA-202 has been working to integrate the SPYDR ear cup into any helmet for any aircraft as advertised for the Navy. The SPYDR device is located inside the helmet of the aircrew. From here, it is able to monitor the measurements described below. (Shender and Wathen 2019).

- Manufacturer: Spotlight Labs
- Cost: $10,000 per helmet retrofit
- Measurements (Person): Pulse Rate, SpO2, Cabin Pressure, Acceleration, Hypoxia Alert
- Measurements (Environmental): N/A
- Weight (oz.): 2.46
- Battery Life (hrs.): 10
- Location on Person: ear
- Design Intent: Aviation

Q. MASES

PMA-202 has been working to integrate this technology to the aircrew's mask. (Shender and Wathen 2019). This device is attached to the aircrew's oxygen hose in order to monitor the measurements described below. The hose is then run to the MASE device the reads these measurements.

- Manufacturer: Intelligent Optical Systems
- Cost: Not Available
- Measurements (Person): In-mask ppCO2
- Measurements (Environmental): N/A
- Weight (oz.): ~ .7
- Battery Life (hrs.): 10
- Location on Person: underneath mask
- Design Intent: Aviation

R. SONITUS INTRA-ORAL SENSOR PLATFORM

PMA-202 has been working to integrate this technology to the naval fleet. As it is currently only available to measure as a molar mic. This molar attachment can monitor the user's in-mas ppCO2. The measurements are then transmitted to a small device that can be attached to the user's body. (Shender and Wathen 2019).

- Manufacturer: Sonitus
- Cost: Not Available
- Measurements (Person): In-mask ppCO2
- Measurements (Environmental): N/A
- Weight (oz.): 0.6
- Battery Life (hrs.): 10
- Location on Person: head (molar)
- Design Intent: Aviation

S. POCKET NIRS – PORTABLE NEAR-INFRARED TISSUE OXYGENATION MONITOR SYSTEM

Small lightweight monitoring device that will attach to the exterior skin of its user to measure the change of the oxygenation concentration within a biological tissue in a non-intrusive manner (DynaSense Inc. n.d.).

- Manufacturer: DynaSense
- Cost: Not Available
- Measurements (Person): SpO2
- Measurements (Environmental): N/A
- Weight (oz.): 3.5
- Battery Life (hrs.): 6
- Location on Person: wrist and arm
- Design Intent: Aviation

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. CHARACTERISTIC EVALUATION RESULTS BY MEASUREMENT

	HUMAN MEASUREMENTS	Heart Rate	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5		Y		2.9	50	Sports	Lower Limb/Wrist		21	100	75	50		63
Slamstick														
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		14	20	100	50		60
AtomTube														
HexoSkin Smart Kit		Y		4.9	12	Sports	Body Core		12	24	75	100		65
GaugeWear														
VivoSmart 4		Y		0.6	168	Sports	Lower Limb/Wrist		100	100	75	50		75
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG		Y												
TrackAid Pulse Monitor		Y												
Garmin Chest Strap		Y		2.08	300	Sports	Body Core		29	100	75	100		79
AWARE		Y		1.1	10	Aviation	Body Core		55	20	100	100		81
MICROS		Y		1.12	10	Aviation	Body Core		54	20	100	100		81
HMAPS		Y		9.1	10	Aviation	Body Core		7	20	100	100		74
SPYDR		Y		2.46	10	Aviation	Head		24	20	100	100		77
MASES														
SONITUS														
Pocket NIRS														

Figure 16. Characteristic Evaluation Results: Heart Rate

	HUMAN MEASUREMENTS	Body Temperature	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel														
AtomTube														
HexoSkin Smart Kit														
GaugeWear		Y		9.1	10	Sports	Body Core		12	20	75	100		65
VivoSmart 4														
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG		Y												
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE		Y		1.1	10	Aviation	Body Core		100	20	100	100		88
MICROS		Y		1.12	10	Aviation	Body Core		98	20	100	100		88
HMAPS		Y		9.1	10	Aviation	Body Core		12	20	100	100		75
SPYDR														
MASES														
SONITUS														
Pocket NIRS														

Figure 17. Characteristic Evaluation Results: Body Temperature

	HUMAN MEASUREMENTS	Carbon Dioxide Output	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel														
AtomTube														
HexoSkin Smart Kit														
GaugeWear														
VivoSmart 4														
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG														
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS														
SPYDR														
MASES		Y		0.7	10	Aviation	Head		86	20	100	100		86
SONITUS		Y		0.6	10	Aviation	Head		100	20	100	100		88
Pocket NIRS														

Figure 18. Characteristic Evaluation Results: Carbon Dioxide Output

	HUMAN MEASUREMENTS	Breathing Rate	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel														
AtomTube														
HexoSkin Smart Kit		Y		4.9	12	Sports	Body Core		100	24	75	100		79
GaugeWear														
VivoSmart 4														
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG		Y												
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS														
SPYDR														
MASES														
SONITUS														
Pocket NIRS														

Figure 19. Characteristic Evaluation Results: Breathing Rate

Device	HUMAN MEASUREMENTS	Blood Oxygen Level	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		14	20	100	50		60
AtomTube														
HexoSkin Smart Kit														
GaugeWear														
VivoSmart 4		Y		0.6	168	Sports	Lower Limb/Wrist		100	100	75	50		75
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG		Y												
TrackAid Pulse Monitor		Y												
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS		Y		9.1	10	Aviation	Body Core		7	20	100	100		74
SPYDR		Y		2.46	10	Aviation	Head		24	20	100	100		77
MASES														
SONITUS														
Pocket NIRS		Y		3.5	10	Aviation	Upper Limb		17	20	100	75		68

Figure 20. Characteristic Evaluation Results: Blood Oxygen Level

	ENVIRONMENTAL MEASUREMENTS	Temperature	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		32	20	100	50		63
AtomTube		Y		1.34	168	Sports	No Contact		100	100	75	100		90
HexoSkin Smart Kit														
GaugeWear														
VivoSmart 4														
Drop D2		Y												
RKI Instruments 72-0341RKC														
Equivital Wearable ECG														
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS														
SPYDR														
MASES														
SONITUS														
Pocket NIRS														

Figure 21. Characteristic Evaluation Results: Environmental Temperature

	ENVIRONMENTAL MEASUREMENTS	Humidity	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		32	20	100	50		63
AtomTube		Y		1.34	168	Sports	No Contact		100	100	75	100		90
HexoSkin Smart Kit														
GaugeWear														
VivoSmart 4														
Drop D2		Y												
RKI Instruments 72-0341RKC														
Equivital Wearable ECG														
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS														
SPYDR														
MASES														
SONITUS														
Pocket NIRS														

Figure 22. Characteristic Evaluation Results: Humidity

	ENVIRONMENTAL MEASUREMENTS	Air Quality/Composition	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick														
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		32	20	100	50		63
AtomTube		Y		1.34	168	Sports	No Contact		100	100	75	100		90
HexoSkin Smart Kit														
GaugeWear														
VivoSmart 4														
Drop D2														
RKI Instruments 72-0341RKC		Y		4.6	20	Industrial	No Contact		29	40	75	100		70
Equivital Wearable ECG														
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS														
SPYDR														
MASES														
SONITUS														
Pocket NIRS														

Figure 23. Characteristic Evaluation Results: Air Quality/Composition

	ENVIRONMENTAL MEASUREMENTS	G Force	DEVICE CHARACTERISTICS	Weight (oz)	Battery Life (hours)	Design Intent	Locations on Body	TECHNICAL EVALUATION	Weight (oz)	Battery Life (hrs)	Design Intent	Location on Body	CHARACTERISTIC RATING	Total Score
Fenix 3/5														
Slamstick		Y		2.29	22	Aviation	No Contact		100	44	100	100		92
Fly Sentinel		Y		4.23	10	Aviation	Lower Limb/Wrist		54	20	100	50		66
AtomTube														
HexoSkin Smart Kit		Y		4.9	12	Sports	Body Core		47	24	75	100		71
GaugeWear														
VivoSmart 4														
Drop D2														
RKI Instruments 72-0341RKC														
Equivital Wearable ECG		Y												
TrackAid Pulse Monitor														
Garmin Chest Strap														
AWARE														
MICROS														
HMAPS		Y		9.1	10	Aviation	Body Core		25	20	100	100		77
SPYDR		Y		2.46	10	Aviation	Head		93	20	100	100		87
MASES														
SONITUS														
Pocket NIRS														

Figure 24. Characteristic Evaluation Results: G-forces

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D. MULTIPLE CONFIGURATION MATLAB OUTPUT

Please note that the "HANDCRAFTED OPTION[S]" is a logical data check within the code and should not be used in the evaluation.

```
sum_no_contact =

 908


 Max Value No_contact:

 0.0 0.0 0.0 0.0 0.0 180.0 90.0 180.0 458.0



sum_HandCraftedOPTION1 =

 1873.5


 Max Value HANDCRAFTED OPTION1:

 406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0


sum_HandCraftedOPTION2 =

 2320.5


 Max Value HANDCRAFTED OPTION2:

 327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0


 Viable 4 device Option Number 1.0
 Max value of all no contact with...
 core device: HexoSkin Smart Kit
 head device: SPYDR
 upper limb device: Pocket NIRS
 wrist device: Fenix 3/5
 383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
 Total Value of Option 1.0: 2068.0


 Viable 4 device Option Number 2.0
 Max value of all no contact with...
```

```
core device: HexoSkin Smart Kit
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 2.0: 2068.0


Viable 4 device Option Number 3.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 3.0: 2068.0


Viable 4 device Option Number 4.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 4.0: 2312.5


Viable 4 device Option Number 5.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 5.0: 2312.5


Viable 4 device Option Number 6.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 344.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 6.0: 2395.0


Viable 4 device Option Number 7.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
upper limb device: Pocket NIRS
```

```
wrist device: Fenix 3/5
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 7.0: 2320.5


Viable 4 device Option Number 8.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 8.0: 2320.5


Viable 4 device Option Number 9.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 352.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 9.0: 2403.0


Viable 4 device Option Number 10.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 10.0: 1805.0


Viable 4 device Option Number 11.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 11.0: 1805.0


Viable 4 device Option Number 12.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 12.0: 1805.0
```

```
Viable 4 device Option Number 13.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 13.0: 2038.0


Viable 4 device Option Number 14.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 14.0: 2023.0


Viable 4 device Option Number 15.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 130.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 15.0: 2132.0


Viable 4 device Option Number 16.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 16.0: 2046.0


Viable 4 device Option Number 17.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 17.0: 2031.0


Viable 4 device Option Number 18.0
```

```
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 130.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 18.0: 2140.0


Viable 4 device Option Number 19.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 19.0: 1688.0


Viable 4 device Option Number 20.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 20.0: 1688.0


Viable 4 device Option Number 21.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 21.0: 1688.0


Viable 4 device Option Number 22.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 22.0: 1989.0


Viable 4 device Option Number 23.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
```

```
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 23.0: 1989.0


Viable 4 device Option Number 24.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
396.5 0.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 24.0: 2023.5


Viable 4 device Option Number 25.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 25.0: 1997.0


Viable 4 device Option Number 26.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 26.0: 1997.0


Viable 4 device Option Number 27.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
396.5 0.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 27.0: 2031.5


Viable 4 device Option Number 28.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
```

```
Total Value of Option 28.0: 1873.5


Viable 4 device Option Number 29.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 29.0: 1873.5


Viable 4 device Option Number 30.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 30.0: 1873.5


Viable 4 device Option Number 31.0
Max value of all no contact with...
core device: AWARE
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 31.0: 2174.5


Viable 4 device Option Number 32.0
Max value of all no contact with...
core device: AWARE
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 32.0: 2174.5


Viable 4 device Option Number 33.0
Max value of all no contact with...
core device: AWARE
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
406.0 176.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 33.0: 2209.0
```

```
Viable 4 device Option Number 34.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 34.0: 2182.5


Viable 4 device Option Number 35.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 35.0: 2182.5


Viable 4 device Option Number 36.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
406.0 176.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 36.0: 2217.0


Viable 4 device Option Number 37.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 37.0: 1872.5


Viable 4 device Option Number 38.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 38.0: 1872.5


Viable 4 device Option Number 39.0
Max value of all no contact with...
core device: MICROS
```

```
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 39.0: 1872.5


Viable 4 device Option Number 40.0
Max value of all no contact with...
core device: MICROS
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 40.0: 2173.5


Viable 4 device Option Number 41.0
Max value of all no contact with...
core device: MICROS
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 41.0: 2173.5


Viable 4 device Option Number 42.0
Max value of all no contact with...
core device: MICROS
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
405.0 176.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 42.0: 2208.0


Viable 4 device Option Number 43.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 43.0: 2181.5


Viable 4 device Option Number 44.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
```

405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 44.0: 2181.5

Viable 4 device Option Number 45.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
405.0 176.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 45.0: 2216.0

Viable 4 device Option Number 46.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 46.0: 1825.0

Viable 4 device Option Number 47.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 47.0: 1825.0

Viable 4 device Option Number 48.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 48.0: 1825.0

Viable 4 device Option Number 49.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 49.0: 2142.0

```
Viable 4 device Option Number 50.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 50.0: 2142.0


Viable 4 device Option Number 51.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 150.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 51.0: 2152.0


Viable 4 device Option Number 52.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 52.0: 2150.0


Viable 4 device Option Number 53.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 53.0: 2150.0


Viable 4 device Option Number 54.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 150.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 54.0: 2160.0


Viable 3 device Option Number 55.0
Max value of all no contact with...
```

```
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 55.0: 1675.0


Viable 3 device Option Number 56.0
Max value of all no contact with...
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 56.0: 1675.0


Viable 3 device Option Number 57.0
Max value of all no contact with...
head device: SPYDR
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 57.0: 1675.0


Viable 3 device Option Number 58.0
Max value of all no contact with...
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 58.0: 1908.0


Viable 3 device Option Number 59.0
Max value of all no contact with...
head device: MASES
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 59.0: 1893.0


Viable 3 device Option Number 60.0
Max value of all no contact with...
head device: MASES
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 60.0: 2002.0


Viable 3 device Option Number 61.0
```

```
Max value of all no contact with...
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 61.0: 1916.0


Viable 3 device Option Number 62.0
Max value of all no contact with...
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 62.0: 1901.0


Viable 3 device Option Number 63.0
Max value of all no contact with...
head device: SONITUS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 63.0: 2010.0


Viable 3 device Option Number 64.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 64.0: 1968.5


Viable 3 device Option Number 65.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 65.0: 1968.5


Viable 3 device Option Number 66.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 0.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 66.0: 2051.0
```

```
Viable 3 device Option Number 67.0
Max value of all no contact with...
core device: GaugeWear
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 67.0: 1694.0


Viable 3 device Option Number 68.0
Max value of all no contact with...
core device: GaugeWear
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 68.0: 1679.0


Viable 3 device Option Number 69.0
Max value of all no contact with...
core device: GaugeWear
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 130.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 69.0: 1788.0


Viable 3 device Option Number 70.0
Max value of all no contact with...
core device: Garmin Chest Strap
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 70.0: 1645.0


Viable 3 device Option Number 71.0
Max value of all no contact with...
core device: Garmin Chest Strap
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 71.0: 1645.0


Viable 3 device Option Number 72.0
Max value of all no contact with...
core device: Garmin Chest Strap
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
396.5 0.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 72.0: 1679.5
```

```
Viable 3 device Option Number 73.0
Max value of all no contact with...
core device: AWARE
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
406.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 73.0: 1830.5


Viable 3 device Option Number 74.0
Max value of all no contact with...
core device: AWARE
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
406.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 74.0: 1830.5


Viable 3 device Option Number 75.0
Max value of all no contact with...
core device: AWARE
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
406.0 176.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 75.0: 1865.0


Viable 3 device Option Number 76.0
Max value of all no contact with...
core device: MICROS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
405.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 76.0: 1829.5


Viable 3 device Option Number 77.0
Max value of all no contact with...
core device: MICROS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
405.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 77.0: 1829.5


Viable 3 device Option Number 78.0
Max value of all no contact with...
core device: MICROS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
405.0 176.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 78.0: 1864.0
```

```
Viable 3 device Option Number 79.0
Max value of all no contact with...
core device: HMAPS
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
370.0 150.0 0.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 79.0: 1798.0


Viable 3 device Option Number 80.0
Max value of all no contact with...
core device: HMAPS
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
370.0 150.0 0.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 80.0: 1798.0


Viable 3 device Option Number 81.0
Max value of all no contact with...
core device: HMAPS
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 150.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 81.0: 1808.0


Viable 3 device Option Number 82.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
wrist device: Fenix 3/5
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 82.0: 2068.0


Viable 3 device Option Number 83.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
wrist device: Fly Sentinel
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 83.0: 2068.0


Viable 3 device Option Number 84.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
wrist device: VivoSmart 4
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
```

```
Total Value of Option 84.0: 2068.0


Viable 3 device Option Number 85.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
wrist device: Fenix 3/5
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 85.0: 2312.5


Viable 3 device Option Number 86.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
wrist device: Fly Sentinel
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 86.0: 2312.5


Viable 3 device Option Number 87.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
wrist device: VivoSmart 4
375.0 0.0 344.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 87.0: 2395.0


Viable 3 device Option Number 88.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
wrist device: Fenix 3/5
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 88.0: 2320.5


Viable 3 device Option Number 89.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
wrist device: Fly Sentinel
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 89.0: 2320.5


Viable 3 device Option Number 90.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
wrist device: VivoSmart 4
```

```
375.0 0.0 352.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 90.0: 2403.0


Viable 3 device Option Number 91.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
wrist device: Fenix 3/5
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 91.0: 1805.0


Viable 3 device Option Number 92.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
wrist device: Fly Sentinel
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 92.0: 1805.0


Viable 3 device Option Number 93.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
wrist device: VivoSmart 4
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 93.0: 1805.0


Viable 3 device Option Number 94.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
wrist device: Fenix 3/5
315.5 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 94.0: 2038.0


Viable 3 device Option Number 95.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
wrist device: Fly Sentinel
300.5 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 95.0: 2023.0


Viable 3 device Option Number 96.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
```

```
wrist device: VivoSmart 4
375.0 130.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 96.0: 2132.0


Viable 3 device Option Number 97.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
wrist device: Fenix 3/5
315.5 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 97.0: 2046.0


Viable 3 device Option Number 98.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
wrist device: Fly Sentinel
300.5 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 98.0: 2031.0


Viable 3 device Option Number 99.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
wrist device: VivoSmart 4
375.0 130.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 99.0: 2140.0


Viable 3 device Option Number 100.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
wrist device: Fenix 3/5
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 100.0: 1688.0


Viable 3 device Option Number 101.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
wrist device: Fly Sentinel
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 101.0: 1688.0


Viable 3 device Option Number 102.0
Max value of all no contact with...
core device: Garmin Chest Strap
```

```
head device: SPYDR
wrist device: VivoSmart 4
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 102.0: 1688.0


Viable 3 device Option Number 103.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
wrist device: Fenix 3/5
396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 103.0: 1989.0


Viable 3 device Option Number 104.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
wrist device: Fly Sentinel
396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 104.0: 1989.0


Viable 3 device Option Number 105.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
wrist device: VivoSmart 4
396.5 0.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 105.0: 2023.5


Viable 3 device Option Number 106.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
wrist device: Fenix 3/5
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 106.0: 1997.0


Viable 3 device Option Number 107.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
wrist device: Fly Sentinel
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 107.0: 1997.0


Viable 3 device Option Number 108.0
Max value of all no contact with...
```

core device: Garmin Chest Strap
head device: SONITUS
wrist device: VivoSmart 4
396.5 0.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 108.0: 2031.5

Viable 3 device Option Number 109.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
wrist device: Fenix 3/5
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 109.0: 1873.5

Viable 3 device Option Number 110.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
wrist device: Fly Sentinel
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 110.0: 1873.5

Viable 3 device Option Number 111.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
wrist device: VivoSmart 4
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 111.0: 1873.5

Viable 3 device Option Number 112.0
Max value of all no contact with...
core device: AWARE
head device: MASES
wrist device: Fenix 3/5
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 112.0: 2174.5

Viable 3 device Option Number 113.0
Max value of all no contact with...
core device: AWARE
head device: MASES
wrist device: Fly Sentinel
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 113.0: 2174.5

Viable 3 device Option Number 114.0

```
Max value of all no contact with...
core device: AWARE
head device: MASES
wrist device: VivoSmart 4
406.0 176.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 114.0: 2209.0


Viable 3 device Option Number 115.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
wrist device: Fenix 3/5
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 115.0: 2182.5


Viable 3 device Option Number 116.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
wrist device: Fly Sentinel
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 116.0: 2182.5


Viable 3 device Option Number 117.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
wrist device: VivoSmart 4
406.0 176.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 117.0: 2217.0


Viable 3 device Option Number 118.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
wrist device: Fenix 3/5
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 118.0: 1872.5


Viable 3 device Option Number 119.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
wrist device: Fly Sentinel
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 119.0: 1872.5
```

```
Viable 3 device Option Number 120.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
wrist device: VivoSmart 4
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 120.0: 1872.5


Viable 3 device Option Number 121.0
Max value of all no contact with...
core device: MICROS
head device: MASES
wrist device: Fenix 3/5
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 121.0: 2173.5


Viable 3 device Option Number 122.0
Max value of all no contact with...
core device: MICROS
head device: MASES
wrist device: Fly Sentinel
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 122.0: 2173.5


Viable 3 device Option Number 123.0
Max value of all no contact with...
core device: MICROS
head device: MASES
wrist device: VivoSmart 4
405.0 176.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 123.0: 2208.0


Viable 3 device Option Number 124.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
wrist device: Fenix 3/5
405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 124.0: 2181.5


Viable 3 device Option Number 125.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
wrist device: Fly Sentinel
405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 125.0: 2181.5
```

```
Viable 3 device Option Number 126.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
wrist device: VivoSmart 4
405.0 176.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 126.0: 2216.0


Viable 3 device Option Number 127.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
wrist device: Fenix 3/5
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 127.0: 1825.0


Viable 3 device Option Number 128.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
wrist device: Fly Sentinel
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 128.0: 1825.0


Viable 3 device Option Number 129.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
wrist device: VivoSmart 4
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 129.0: 1825.0


Viable 3 device Option Number 130.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
wrist device: Fenix 3/5
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 130.0: 2142.0


Viable 3 device Option Number 131.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
wrist device: Fly Sentinel
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 131.0: 2142.0
```

```
Viable 3 device Option Number 132.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
wrist device: VivoSmart 4
375.0 150.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 132.0: 2152.0


Viable 3 device Option Number 133.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
wrist device: Fenix 3/5
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 133.0: 2150.0


Viable 3 device Option Number 134.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
wrist device: Fly Sentinel
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 134.0: 2150.0


Viable 3 device Option Number 135.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
wrist device: VivoSmart 4
375.0 150.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 135.0: 2160.0


Viable 3 device Option Number 136.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
upper limb device: Pocket NIRS
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 136.0: 2068.0


Viable 3 device Option Number 137.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
upper limb device: Pocket NIRS
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
```

```
Total Value of Option 137.0: 2312.5


Viable 3 device Option Number 138.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
upper limb device: Pocket NIRS
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 138.0: 2320.5


Viable 3 device Option Number 139.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
upper limb device: Pocket NIRS
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 139.0: 1805.0


Viable 3 device Option Number 140.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
upper limb device: Pocket NIRS
0.0 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 140.0: 1722.5


Viable 3 device Option Number 141.0
Max value of all no contact with...
core device: GaugeWear
head device: SONITUS
upper limb device: Pocket NIRS
0.0 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 141.0: 1730.5


Viable 3 device Option Number 142.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
upper limb device: Pocket NIRS
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 142.0: 1688.0


Viable 3 device Option Number 143.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
upper limb device: Pocket NIRS
```

396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 143.0: 1989.0

Viable 3 device Option Number 144.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
upper limb device: Pocket NIRS
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 144.0: 1997.0

Viable 3 device Option Number 145.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
upper limb device: Pocket NIRS
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 145.0: 1873.5

Viable 3 device Option Number 146.0
Max value of all no contact with...
core device: AWARE
head device: MASES
upper limb device: Pocket NIRS
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 146.0: 2174.5

Viable 3 device Option Number 147.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
upper limb device: Pocket NIRS
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 147.0: 2182.5

Viable 3 device Option Number 148.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
upper limb device: Pocket NIRS
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 148.0: 1872.5

Viable 3 device Option Number 149.0
Max value of all no contact with...
core device: MICROS
head device: MASES

```
upper limb device: Pocket NIRS
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 149.0: 2173.5


Viable 3 device Option Number 150.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
upper limb device: Pocket NIRS
405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 150.0: 2181.5


Viable 3 device Option Number 151.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
upper limb device: Pocket NIRS
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 151.0: 1825.0


Viable 3 device Option Number 152.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
upper limb device: Pocket NIRS
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 152.0: 2142.0


Viable 3 device Option Number 153.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
upper limb device: Pocket NIRS
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 153.0: 2150.0


Viable 3 device NON-COTS ONLY OptionNumber 154.0
Max value with...
core device: AWARE
head device: SPYDR
upper limb device: Pocket NIRS
406.0 176.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 154.0: 1400.5


Viable 3 device NON-COTS ONLY OptionNumber 155.0
Max value with...
core device: AWARE
```

```
head device: MASES
upper limb device: Pocket NIRS
406.0 176.0 344.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 155.0: 1266.5


Viable 3 device NON-COTS ONLY OptionNumber 156.0
Max value with...
core device: AWARE
head device: SONITUS
upper limb device: Pocket NIRS
406.0 176.0 352.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 156.0: 1274.5


Viable 3 device NON-COTS ONLY OptionNumber 157.0
Max value with...
core device: MICROS
head device: SPYDR
upper limb device: Pocket NIRS
405.0 176.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 157.0: 1399.5


Viable 3 device NON-COTS ONLY OptionNumber 158.0
Max value with...
core device: MICROS
head device: MASES
upper limb device: Pocket NIRS
405.0 176.0 344.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 158.0: 1265.5


Viable 3 device NON-COTS ONLY OptionNumber 159.0
Max value with...
core device: MICROS
head device: SONITUS
upper limb device: Pocket NIRS
405.0 176.0 352.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 159.0: 1273.5


Viable 3 device NON-COTS ONLY OptionNumber 160.0
Max value with...
core device: HMAPS
head device: SPYDR
upper limb device: Pocket NIRS
383.5 150.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 160.0: 1352.0


Viable 3 device NON-COTS ONLY OptionNumber 161.0
Max value with...
```

```
core device: HMAPS
head device: MASES
upper limb device: Pocket NIRS
370.0 150.0 344.0 0.0 370.0 0.0 0.0 0.0 384.0
Total Value of Option 161.0: 1618.0


Viable 3 device NON-COTS ONLY OptionNumber 162.0
Max value with...
core device: HMAPS
head device: SONITUS
upper limb device: Pocket NIRS
370.0 150.0 352.0 0.0 370.0 0.0 0.0 0.0 384.0
Total Value of Option 162.0: 1626.0


Viable 2 device Option Number 163.0
Max value of all no contact with...
upper limb device: Pocket NIRS
wrist device: Fenix 3/5
315.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 163.0: 1564.0


Viable 2 device Option Number 164.0
Max value of all no contact with...
upper limb device: Pocket NIRS
wrist device: Fly Sentinel
300.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 164.0: 1549.0


Viable 2 device Option Number 165.0
Max value of all no contact with...
upper limb device: Pocket NIRS
wrist device: VivoSmart 4
375.0 0.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 165.0: 1658.0


Viable 2 device Option Number 166.0
Max value of all no contact with...
head device: SPYDR
wrist device: Fenix 3/5
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 166.0: 1675.0


Viable 2 device Option Number 167.0
Max value of all no contact with...
head device: SPYDR
wrist device: Fly Sentinel
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
```

```
Total Value of Option 167.0: 1675.0


Viable 2 device Option Number 168.0
Max value of all no contact with...
head device: SPYDR
wrist device: VivoSmart 4
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 168.0: 1675.0


Viable 2 device Option Number 169.0
Max value of all no contact with...
head device: MASES
wrist device: Fenix 3/5
315.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 169.0: 1908.0


Viable 2 device Option Number 170.0
Max value of all no contact with...
head device: MASES
wrist device: Fly Sentinel
300.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 170.0: 1893.0


Viable 2 device Option Number 171.0
Max value of all no contact with...
head device: MASES
wrist device: VivoSmart 4
375.0 0.0 344.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 171.0: 2002.0


Viable 2 device Option Number 172.0
Max value of all no contact with...
head device: SONITUS
wrist device: Fenix 3/5
315.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 172.0: 1916.0


Viable 2 device Option Number 173.0
Max value of all no contact with...
head device: SONITUS
wrist device: Fly Sentinel
300.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 173.0: 1901.0


Viable 2 device Option Number 174.0
Max value of all no contact with...
```

```
head device: SONITUS
wrist device: VivoSmart 4
375.0 0.0 352.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 174.0: 2010.0


Viable 2 device Option Number 175.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: Fenix 3/5
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 175.0: 1968.5


Viable 2 device Option Number 176.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: Fly Sentinel
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 176.0: 1968.5


Viable 2 device Option Number 177.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: VivoSmart 4
375.0 0.0 0.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 177.0: 2051.0


Viable 2 device Option Number 178.0
Max value of all no contact with...
core device: GaugeWear
wrist device: Fenix 3/5
315.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 178.0: 1694.0


Viable 2 device Option Number 179.0
Max value of all no contact with...
core device: GaugeWear
wrist device: Fly Sentinel
300.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 179.0: 1679.0


Viable 2 device Option Number 180.0
Max value of all no contact with...
core device: GaugeWear
wrist device: VivoSmart 4
375.0 130.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 180.0: 1788.0
```

```
Viable 2 device Option Number 181.0
Max value of all no contact with...
core device: Garmin Chest Strap
wrist device: Fenix 3/5
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 181.0: 1645.0


Viable 2 device Option Number 182.0
Max value of all no contact with...
core device: Garmin Chest Strap
wrist device: Fly Sentinel
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 182.0: 1645.0


Viable 2 device Option Number 183.0
Max value of all no contact with...
core device: Garmin Chest Strap
wrist device: VivoSmart 4
396.5 0.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 183.0: 1679.5


Viable 2 device Option Number 184.0
Max value of all no contact with...
core device: AWARE
wrist device: Fenix 3/5
406.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 184.0: 1830.5


Viable 2 device Option Number 185.0
Max value of all no contact with...
core device: AWARE
wrist device: Fly Sentinel
406.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 185.0: 1830.5


Viable 2 device Option Number 186.0
Max value of all no contact with...
core device: AWARE
wrist device: VivoSmart 4
406.0 176.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 186.0: 1865.0


Viable 2 device Option Number 187.0
Max value of all no contact with...
core device: MICROS
wrist device: Fenix 3/5
```

```
405.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 187.0: 1829.5


Viable 2 device Option Number 188.0
Max value of all no contact with...
core device: MICROS
wrist device: Fly Sentinel
405.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 188.0: 1829.5


Viable 2 device Option Number 189.0
Max value of all no contact with...
core device: MICROS
wrist device: VivoSmart 4
405.0 176.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 189.0: 1864.0


Viable 2 device Option Number 190.0
Max value of all no contact with...
core device: HMAPS
wrist device: Fenix 3/5
370.0 150.0 0.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 190.0: 1798.0


Viable 2 device Option Number 191.0
Max value of all no contact with...
core device: HMAPS
wrist device: Fly Sentinel
370.0 150.0 0.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 191.0: 1798.0


Viable 2 device Option Number 192.0
Max value of all no contact with...
core device: HMAPS
wrist device: VivoSmart 4
375.0 150.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 192.0: 1808.0


Viable 2 device Option Number 193.0
Max value of all no contact with...
head device: SPYDR
upper limb device: Pocket NIRS
383.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 193.0: 1675.0


Viable 2 device Option Number 194.0
```

```
Max value of all no contact with...
head device: MASES
upper limb device: Pocket NIRS
0.0 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 194.0: 1592.5


Viable 2 device Option Number 195.0
Max value of all no contact with...
head device: SONITUS
upper limb device: Pocket NIRS
0.0 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 195.0: 1600.5


Viable 2 device Option Number 196.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
upper limb device: Pocket NIRS
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 196.0: 1968.5


Viable 2 device Option Number 197.0
Max value of all no contact with...
core device: GaugeWear
upper limb device: Pocket NIRS
0.0 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 197.0: 1378.5


Viable 2 device Option Number 198.0
Max value of all no contact with...
core device: Garmin Chest Strap
upper limb device: Pocket NIRS
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 198.0: 1645.0


Viable 2 device Option Number 199.0
Max value of all no contact with...
core device: AWARE
upper limb device: Pocket NIRS
406.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 199.0: 1830.5


Viable 2 device Option Number 200.0
Max value of all no contact with...
core device: MICROS
upper limb device: Pocket NIRS
405.0 176.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 200.0: 1829.5
```

```
Viable 2 device Option Number 201.0
Max value of all no contact with...
core device: HMAPS
upper limb device: Pocket NIRS
370.0 150.0 0.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 201.0: 1798.0


Viable 2 device Option Number 202.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SPYDR
383.5 0.0 0.0 393.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 202.0: 2068.0


Viable 2 device Option Number 203.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: MASES
327.0 0.0 344.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 203.0: 2312.5


Viable 2 device Option Number 204.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
head device: SONITUS
327.0 0.0 352.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 204.0: 2320.5


Viable 2 device Option Number 205.0
Max value of all no contact with...
core device: GaugeWear
head device: SPYDR
383.5 130.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 205.0: 1805.0


Viable 2 device Option Number 206.0
Max value of all no contact with...
core device: GaugeWear
head device: MASES
0.0 130.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 206.0: 1722.5


Viable 2 device Option Number 207.0
Max value of all no contact with...
core device: GaugeWear
```

```
head device: SONITUS
0.0 130.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 207.0: 1730.5


Viable 2 device Option Number 208.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SPYDR
396.5 0.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 208.0: 1688.0


Viable 2 device Option Number 209.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: MASES
396.5 0.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 209.0: 1989.0


Viable 2 device Option Number 210.0
Max value of all no contact with...
core device: Garmin Chest Strap
head device: SONITUS
396.5 0.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 210.0: 1997.0


Viable 2 device Option Number 211.0
Max value of all no contact with...
core device: AWARE
head device: SPYDR
406.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 211.0: 1873.5


Viable 2 device Option Number 212.0
Max value of all no contact with...
core device: AWARE
head device: MASES
406.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 212.0: 2174.5


Viable 2 device Option Number 213.0
Max value of all no contact with...
core device: AWARE
head device: SONITUS
406.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 213.0: 2182.5
```

```
Viable 2 device Option Number 214.0
Max value of all no contact with...
core device: MICROS
head device: SPYDR
405.0 176.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 214.0: 1872.5


Viable 2 device Option Number 215.0
Max value of all no contact with...
core device: MICROS
head device: MASES
405.0 176.0 344.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 215.0: 2173.5


Viable 2 device Option Number 216.0
Max value of all no contact with...
core device: MICROS
head device: SONITUS
405.0 176.0 352.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 216.0: 2181.5


Viable 2 device Option Number 217.0
Max value of all no contact with...
core device: HMAPS
head device: SPYDR
383.5 150.0 0.0 0.0 383.5 180.0 90.0 180.0 458.0
Total Value of Option 217.0: 1825.0


Viable 2 device Option Number 218.0
Max value of all no contact with...
core device: HMAPS
head device: MASES
370.0 150.0 344.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 218.0: 2142.0


Viable 2 device Option Number 219.0
Max value of all no contact with...
core device: HMAPS
head device: SONITUS
370.0 150.0 352.0 0.0 370.0 180.0 90.0 180.0 458.0
Total Value of Option 219.0: 2150.0


Viable 2 Device COTS ONLY OptionNumber 220.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: Fenix 3/5
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
```

```
Total Value of Option 220.0: 1968.5


Viable 2 Device COTS ONLY OptionNumber 221.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: Fly Sentinel
327.0 0.0 0.0 393.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 221.0: 1968.5


Viable 2 Device COTS ONLY OptionNumber 222.0
Max value of all no contact with...
core device: HexoSkin Smart Kit
wrist device: VivoSmart 4
375.0 0.0 0.0 393.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 222.0: 2051.0


Viable 2 Device COTS ONLY OptionNumber 223.0
Max value of all no contact with...
core device: GaugeWear
wrist device: Fenix 3/5
315.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 223.0: 1694.0


Viable 2 Device COTS ONLY OptionNumber 224.0
Max value of all no contact with...
core device: GaugeWear
wrist device: Fly Sentinel
300.5 130.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 224.0: 1679.0


Viable 2 Device COTS ONLY OptionNumber 225.0
Max value of all no contact with...
core device: GaugeWear
wrist device: VivoSmart 4
375.0 130.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 225.0: 1788.0


Viable 2 Device COTS ONLY OptionNumber 226.0
Max value of all no contact with...
core device: Garmin Chest Strap
wrist device: Fenix 3/5
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 226.0: 1645.0


Viable 2 Device COTS ONLY OptionNumber 227.0
Max value of all no contact with...
```

core device: Garmin Chest Strap
wrist device: Fly Sentinel
396.5 0.0 0.0 0.0 340.5 180.0 90.0 180.0 458.0
Total Value of Option 227.0: 1645.0

Viable 2 Device COTS ONLY OptionNumber 228.0
Max value of all no contact with...
core device: Garmin Chest Strap
wrist device: VivoSmart 4
396.5 0.0 0.0 0.0 375.0 180.0 90.0 180.0 458.0
Total Value of Option 228.0: 1679.5

Viable 2 device NON-COTS ONLY OptionNumber 229.0
Max value with...
head device: SPYDR
upper limb device: Pocket NIRS
396.5 0.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 229.0: 1215.0

Viable 2 device NON-COTS ONLY OptionNumber 230.0
Max value with...
head device: MASES
upper limb device: Pocket NIRS
396.5 0.0 344.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 230.0: 1081.0

Viable 2 device NON-COTS ONLY OptionNumber 231.0
Max value with...
head device: SONITUS
upper limb device: Pocket NIRS
396.5 0.0 352.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 231.0: 1089.0

Viable 2 device NON-COTS ONLY OptionNumber 232.0
Max value with...
core device: AWARE
upper limb device: Pocket NIRS
406.0 176.0 0.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 232.0: 922.5

Viable 2 device NON-COTS ONLY OptionNumber 233.0
Max value with...
core device: MICROS
upper limb device: Pocket NIRS
405.0 176.0 0.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 233.0: 921.5

```
Viable 2 device NON-COTS ONLY OptionNumber 234.0
Max value with...
core device: HMAPS
upper limb device: Pocket NIRS
370.0 150.0 0.0 0.0 370.0 0.0 0.0 0.0 384.0
Total Value of Option 234.0: 1274.0


Viable 2 device NON-COTS ONLY OptionNumber 235.0
Max value with...
core device: AWARE
head device: SPYDR
406.0 176.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 235.0: 1400.5


Viable 2 device NON-COTS ONLY OptionNumber 236.0
Max value with...
core device: AWARE
head device: MASES
406.0 176.0 344.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 236.0: 1266.5


Viable 2 device NON-COTS ONLY OptionNumber 237.0
Max value with...
core device: AWARE
head device: SONITUS
406.0 176.0 352.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 237.0: 1274.5


Viable 2 device NON-COTS ONLY OptionNumber 238.0
Max value with...
core device: MICROS
head device: SPYDR
405.0 176.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 238.0: 1399.5


Viable 2 device NON-COTS ONLY OptionNumber 239.0
Max value with...
core device: MICROS
head device: MASES
405.0 176.0 344.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 239.0: 1265.5


Viable 2 device NON-COTS ONLY OptionNumber 240.0
Max value with...
core device: MICROS
head device: SONITUS
```

```
405.0 176.0 352.0 0.0 340.5 0.0 0.0 0.0 0.0
Total Value of Option 240.0: 1273.5


Viable 2 device NON-COTS ONLY OptionNumber 241.0
Max value with...
core device: HMAPS
head device: SPYDR
383.5 150.0 0.0 0.0 383.5 0.0 0.0 0.0 435.0
Total Value of Option 241.0: 1352.0


Viable 2 device NON-COTS ONLY OptionNumber 242.0
Max value with...
core device: HMAPS
head device: MASES
370.0 150.0 344.0 0.0 370.0 0.0 0.0 0.0 384.0
Total Value of Option 242.0: 1618.0


Viable 2 device NON-COTS ONLY OptionNumber 243.0
Max value with...
core device: HMAPS
head device: SONITUS
370.0 150.0 352.0 0.0 370.0 0.0 0.0 0.0 384.0
Total Value of Option 243.0: 1626.0
```

Published with MATLAB® R2018b

SUPPLEMENTAL 1. ALTERNATIVES MATRIX

The devices matrix is a parametrically written Excel workbook that is used in the analysis of devices characteristic evaluations detailed in Chapter III and Chapter IV. The devices matrix was designed to take inputs on the parametric characteristics of each device and conduct analysis through coded calculations. The devices evaluated in the devices matrix were assumed to have passed the go/no-go criteria beforehand. As noted in Chapters III and IV4, the parameter weights for each performance characteristic were defined by the SME on Human SE NAWCADPAX resulting in the devices matrix producing results that have been critically evaluated based on the Navy's need. To obtain the supplemental, use the link available with the main thesis's catalog entry in the NPS Institutional Archive, Calhoun, or to contact the NPS library.

THIS PAGE INTENTIONALLY LEFT BLANK

SUPPLEMENTAL 2. MATLAB CODE

This MATLAB code was used to generate the results in Appendix D. This code is designed to identify the optimal combination of COTS sensor suites for use. The sensors receive a technical parameter rating and undergo the characteristic evaluation as discussed in Chapter III, and are then then transferred into the MATLAB code to determine which combination of sensors will provide the optimal readings from the aircrew during a mission. The inputs are based on the desired number of sensors on the body, location on the body, and options available. Then they are evaluated against other sensors that take the same measurement and chooses the best out of 243 combinations. The sensor suites combinations show a rating within the MATLAB code which matches what was given to each sensor in the multiple configuration evaluation in ch.3, then outputs the results based on the combination with the highest rating. It should be noted, the maximum number of sensors within the suite is 4 and the minimum is 2. To obtain the supplemental, use the link available with the main thesis's catalog entry in the NPS Institutional Archive, Calhoun, or to contact the NPS library.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Amazon. 1996. *Garmin Chest Strap HRM.* Accessed September 10, 2019. https://www.amazon.com/Garmin-HRM-Tri-Heart-Rate-Monitor/dp/B012H8IPQS/ref=sr_1_4?crid=3SSVGJR3BBR1W&keywords=garmin.

Athena GTX Inc. 2019. *ATHENAGTX.* Accessed September 5, 2019. https://athenagtx.com/rd-2/hmaps/.

Atomtube. 2015. *The Portable Air Pollution Monitor.* Accessed September 06, 2019. https://atmotube.com/.

Carre Technologies Inc. 2019. *Hexoskin Smart Kit - Men's.* Accessed September 9, 2019. https://www.hexoskin.com/products/hexoskin-smart-kit-mens.

Delgado Alonso, Jesus, David Berry, and Narciso Guzman. 2018. *Sensor Integrated Pilot Mask for On-Board, Real-Time, Monitoring of Pilot Breathing Gas.* Albuquerque: 48th International Conference on Environmental Systems .

Department of Defense. 1983. "MIL-E-18927E, Military Specification: Environmental Control Systems, Aircraft, General Requirements For (18 AUG 1983)." *EverySpec.* Aug 18. Accessed October 23, 2019. http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-E/MIL-E-18927E_11721/.

———. 2007. "MIL-STD-461F, Department Of Defense Interface Standard: Requirements For The Control Of Electromagnetic Interference Characteristics Of Subsystems And Equipment (10 DEC 2007)." *Every Spec.* December 10. Accessed October 23, 2019. http://everyspec.com/MIL-STD/MIL-STD-0300-0499/MIL-STD-461F_19035/.

DynaSense Inc. n.d. *Wireless Data Transmission and Highly Advanced Portable Near-Infrared Tissue Oxygenation Monitor System (Pocket NIRS).* Accessed September 20, 2019. https://www.dynasense.co.jp/english/product3.html.

Eckstein, Megan. 2019. *Navy Taking Major Steps to Prevent Future Physiological Events in Jets.* USNI News. May 2. Accessed October 23, 2019. https://news.usni.org/2019/05/02/navy-taking-major-steps-to-prevent-future-physiological-episodes-in-jets#more-52086.

———. 2017. *Physiological Episodes Down in the Navy After Slew of Changes; New Pilot Production Rate Nearly Back to Normal.* USNI News. November 9. Accessed September 10, 2019. https://news.usni.org/2017/11/09/physiological-episodes-navy-slew-changes-new-pilot-production-rate-nearly-back-normal#more-29325.

Equivital. 2019. *Equivatal Starter Pack (Single).* Accessed September 09, 2019. https://www.adinstruments.com/products/equivital-starter-pack-single.

Fleet Support Team, Aircrew Oxygen Systems. 2019. *Hypoxia Mitigation Efforts and on the Horizon.* Patuxent River.

FlySentinel. 2018. *FlySentinel.* Accessed September 09, 2019. http://flysentinel.eu/#specifications.

Garmin. 2019. *Garmin Fenix 3.* Accessed September 10, 2019. https://buy.garmin.com/en-US/US/p/160512.

———. 1996. *Garmin Vivosmart 4: Fitness Activity Tracker: Pulse Ox.* Accessed September 10, 2019. https://buy.garmin.com/en-US/US/p/605739#overview.

Gaugewear Inc. n.d. *gaugewear.* Accessed August 19, 2019. http://gaugewear.com/.

General Services Administration. 2019. "beta.SAM.gov." December 23. Accessed December 15, 2020. https://beta.sam.gov/opp/5181f105b9b9416c91feda750cef6713/view?keywords=physiological%20monitoring%20fabrics&sort=-relevance&index=opp&is_active=true&page=1.

Joyner, Sara. 2018. *Naval Aviation News.* June 06. Accessed July 28, 2019. https://navalaviationnews.navylive.dodlive.mil/2018/06/06/physiological-episodes/.

Midé Technology Corporation. 2019. *SlamStick Datasheets Download Page.* Accessed October 23, 2019. https://www.mide.com/slam-stick-datasheets-download-page.

Navy Office of Information. 2017. "Results of Comprehensive Review of Physiological Episodes Released." *America's Navy: Forged by the Sea.* June 15. Accessed September 6, 2019. https://www.navy.mil/submit/display.asp?story_id=101062.

Nielsen-Kellerman Co. 2019. *Kestrel Meters Official Site - Kestrel Wind & Weather Meters.* Accessed September 10, 2019. https://kestrelinstruments.com/kestrel-drop-d2-humidity-logger?gclid=CjwKCAjwzdLrBRBiEiwAEHrAYpHwr1oYgRUCtjsCgcChVWsqSsbAXO0GZBXVRVj1LPRurU-Msd7s7xoCWAQQAvD_Bw.

Phillips, J.B., S.A. Warner, and D.J. Geyer. 2016. *Mitigation of Hypoxia Like Physiological Episodes Through Commercial Off the Shelf Sensing Technologies: NAMRU-D Report Number 16–90.* PDF, Dayton, Ohio: MANRU-Dayton.

Schmitz, Carsten. n.d. "LimeSurvey - The Online Survey Tool." *LimeSurvey.* Accessed October 15, 2019. https://www.limesurvey.org/.

SECNAV. 2017. *ANNEX D: PHYSIOLOGICAL EPISODE.* Accessed July 28, 2019. https://www.secnav.navy.mil/foia/readingroom/HotTopics/T-45 Aircraft Goshawk PE Report/ANX D-1 PE TYPE DESCRIPTIONS FINAL.pdf.

Shender, Barry, and Joel Wathen. 2019. "Aircrew Physiological Monitoring Efforts, NAVAIR PMA 202."

Sonitus. 2019. *Sonitus Sensory Interface Platform.* Accessed September 05, 2019. http://www.sonitustechnologies.com/sonitus-platform/.

Spotlight Labs. 2019. *SPYDR.* Accessed September 5, 2019. http://spotlightlabs2.com/.

TrackAid. 1996. *TrackAid Pulse Oximeter Portable Finger Oxygen Saturation and Pulse Rate Monitor.* Accessed September 10, 2019. https://www.amazon.com/TrackAid-Portable-Saturation-Monitor-Display/dp/B07BNL9M4C/ref=sr_1_4?crid=3NREQUSEX7YZB&keywords=trackaid%20pulse%20oximeter&qid=1566880296&s=gateway&sprefix=trackaid%20,aps,205&sr=8-4.

Transcat Inc. 2018. *RKI Instruments 72–0314RKC.* Accessed September 10, 2019. https://www.transcat.com/rki-instruments-72-0314rkc-72-0314rkc?st-t=adword_google_*&utm_source=google&utm_medium=cpc&adpos=1o22&scid=scplp72-0314RKC&sc_intid=72-0314RKC&gclid=CjwKCAjwzdLrBRBiEiwAEHrAYqW2fPjq0ive7EV8fMQ25sV5ChzDb4bSh9fHvYysVQ_QgxIo8w3WxhoC.

Trimble, Stephen. 2011. *Flight International.* May 117. Accessed July 22, 2019. http://libproxy.nps.edu/login?url=https://search-proquest-com.libproxy.nps.edu/docview/872257946?accountid=12702.

Vivonics Inc. 2015–2020. *Active Wearable for Assessment and Remote Evaluation (AWARE).* Accessed September 10, 2019. https://www.vivonics.com/technologies//aware.

———. 2015–2020. *Wearable Physiological Sensor.* Accessed September 20, 2019. https://www.vivonics.com/technologies/micros.

Wright, LT Craig, and Brian Winder. 2017. *Demonstration of the Digital Joint Helmet Mounted Cueing System (DJHMCS) and Canary Pilot Health Monitoring System as Integrated on the F/A-18F Aircraft.* PDF, China Lake, CA: NAVAIR.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California