Tactile Situation Awareness System Final Report

U.S. Army Aeromedical Research Laboratory

Final Report Date: 01/15/2012

COALITION WARFARE PROGRAM
OUSD AT&L INTERNATIONAL COOPERATION

Tactile Situation Awareness System Final Report

U.S. Army Aeromedical Research Laboratory

January 2012

Table of Contents

1 Introduction

1.1 Executive Summary

The purpose of the CWP Tactile Situation Awareness System (TSAS) program is to deliver a technology to the aviation helicopter community that will reduce the workload of pilots, increase the situation awareness of pilots, and reduce the incidence of helicopter Degraded Visual Environment (DVE) mishaps, especially brownout mishaps in the desert environment. TSAS is a garment containing tactile stimulators (tactors) partially covering the torso that provide aircraft flight control parameters through the sense of touch in an intuitive fashion. During both simulation and in-flight tests prior to the CWP effort, pilots have demonstrated the ability to non-visually hover helicopters and transition to forward flight, while consistently reporting reduced workload and increased situation awareness.

At the beginning of the CWP effort in 2008 the "state-of-the-art" for garments with embedded tactors was twofold: 1) an aircooled vest with three rows of pneumatic tactors (8 tactors per row) and 2) a single belt with 8 early generation electromechanical tactors. Both systems provided drift information in the azimuth.

The deliverables of the CWP project included:

1) Develop an all electromechanical system with improved tactors and wiring.
2) Develop a garment with full torso coverage capable of intuitive targeting, hovering and pitch & roll capabilities.
3) Develop electronics systems with airworthy release (AWR) that can be used for further development by the DT/OT communities.

Although the project provided all the deliverables, the transition of TSAS to the warfighter via the acquisition and DT/OT communities still needs to be accomplished.

1.2 Background

In the initial proposal to the CWP in 2007 the budget request was $ 2.4 million which was the estimate to accomplish the engineering design and construction of the proposed effort. The CWP did not fund the proposal due to limited funds available. During 2007 we submitted an SBIR topic via Naval Air Systems Command (NAVAIR) that could assist in the delivery of the desired products. After the SBIR was approved late 2007, the second CWP proposal was submitted in

2008 with a budget request of $1.1 million in anticipation of two phase 2 SBIRs being awarded to provide the additional support of $ 1.7 million.

The two SBIR companies selected were Engineering Acoustics Inc. (EAI) and Chesapeake Technologies Inc. (CTI). The role of EAI was to design & develop enhanced tactile stimulators as well as develop electronics to drive the new tactors. CTI's role was to integrate the tactors and electronics into a garment and provide the avionics interface(s) compatible with the wide variety of sensors in military and civilian aviation platforms as well as systems capable of operation on legacy aircraft without GPS and INS sensors.

The initial kickoff meeting was hosted at the US Army Aeromedical Research Laboratory (USAARL) February 2008 with representatives from CWP, Defence Research and Development Canada – Toronto (DRDC-Toronto), Canadian Embassy and Naval Aviation Systems Command (NAVAIR). The program goals and interaction between various components was planned for a two year program. Subsequently the CWP office requested the program be extended one year to accommodate funding changes from DoD. The extension to three years proved beneficial due to the prolonged time required to initiate contracts for Phase I and Phase II efforts by the SBIR program office.

Engineering Acoustics Inc. Deliverables

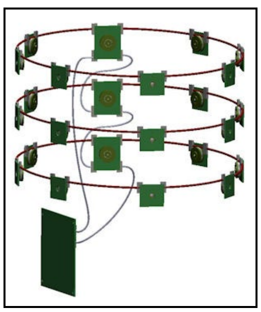
Under a previous SBIR, EAI developed the C-2 tactor which has become the industry standard whenever a robust, reliable tactile stimulator was required. The weaknesses of the C-2 from the perspective of this program were weight, expense and number of wires required to connect the pilot garment to the aircraft umbilical. The C-3 is a smaller derivative as shown beside the C-2 tactor in the photo below.

Photos of C-2 Tactor, C-3 Tactor and EMR Tactor

EAI developed the EMR tactor to complement the C-2. The advantages of the EMR compared to the C-2 include reduced weight, the opportunity to slightly vary the frequency and amplitude of the stimulus and cost reduction in manufacturing.

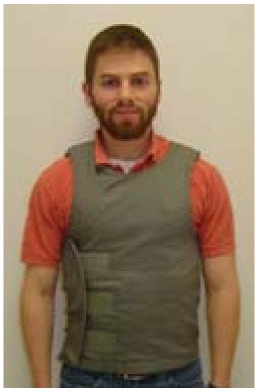
During the development of the new tactors, two advances to address the issue of excessive wiring in the umbilical between the aircraft and the garment were developed. The first was the use of wireless communication using bluetoooth applications. The Army has recently approved wireless headsets for aircrew and the Air Warrior program office is planning wireless applications in future aircrew garments.

The second solution to reduce the number of umbilical wires is the use of a common system of stimulating both the C-2 and EMR tactors via a distributed system using addressable boards in the garment. Although the distributed system considerably simplifies the umbilical wiring and reduces the complexity of the breakaway umbilical issues, there is a penalty paid in increased garment weight due to the addition of addressable boards. The distributed system provides increased reliability in that a failure of any one wire can be compensated by rerouting the signal through a different channel. This system will work well for the DT/OT phase of development. It is anticipated that the final product will incorporate small, rugged Application-Specific Integrated Circuit (ASIC) chips or Flip Chips (also known as Controlled Collapse Chip Connection or its acronym, **C4)** to further reduce weight and increase ruggedness and reliability in austere environments. The concept is diagrammed below.



Chesapeake Technologies Inc. Deliverables

The integration or embedding of tactors and wiring into military approved garments while ensuring a consistent contact interface in close proximity to the skin is a difficult task. CTI has successfully incorporated the distributed system into garments that will be used for DT/OT testing. The below photo is the full torso garment on the left with a distributed tactor system and on the right is the seat cushion with 8 additional tactors before incorporation into the H-60 seat cushion.



EAI has continued improving the belt system which together with the seat and shoulder harness embedded tactors will likely be the first system implemented in military helicopters during the spiral development toward the full torso coverage in an Air Warrior garment. This sequential development was recommended by USAF and Army special operations pilots during the development of the TSAS JORD by SOCOM.

The development of software programs and hardware that can be interfaced with a variety of military helicopter platforms including legacy aircraft was accomplished by incorporating several bus types (e.g. 1553 and ARINC connectivity) as well as an EGI (combined INS and GPS) for legacy aircraft.

-

The black box on the left contains both an EGI (front two thirds) and the TSAS electronics (rear third) for a fully self contained system to permit flight testing in legacy aircraft with minimal avionics or lacking 1553 / ARINC connectivity. The interfaces on the front include connections for 1553 and/or ARINC buss, power, pilot control unit and outputs to TSAS seats, belt or vest torso garment and shoulder harness tactors.

The cockpit interface on the right provides control to the pilots to select the desired modes of operation, for example on/off, hover; glide path and/or navigation.

The CTI system has passed all EMI (Electro-Magnetic Interference) testing and has been integrated with the USAARL H-60 in Ft Rucker and the NACRA UH-1N at NAVAIR.

Canadian Contributions:

The contributions to TSAS from Canada have been continuing for many years. The first garment used for the TSAS program was developed at DCIEM (Defence and Civil Institute of Environmental Medicine) more recently renamed Defence Research and Development Canada – Toronto. The initial air cooled garment was developed commercially by Mustang Survival headquartered in Vancouver B.C.

In the current CWP funded effort, CTI has continued the relationship with Mustang to incorporate tactors and electronics into the torso garments developed in Vancouver.

DRDC-Toronto under the guidance of Dr Bob Cheung has for the past several years continuously sponsored in-flight research using TSAS in combination with novel visual displays (e.g. BOSS developed at NASA Ames). Dr Cheung has additionally funded simulator-based research at USAARL for the past two years to determine the value of TSAS for helicopter Search and Rescue (SAR) operations. This data has been collected and following analysis will be sent as an addenda to this report when completed.

1.3 Operational Requirements

The first formal operational document specific to TSAS is the Joint Operational Requirements Document (JORD) for the Special Operations Forces (SOF) signed 29 July 2003 by VADM Eric Olson Deputy Commander SOCOM.

More recently two additional Army acquisition requirements documents have been signed:

1) Initial Capabilities Document (ICD) for Aircraft Survivability to include Degraded Visual Environments (DVE) was signed October 2011. The ICD was preceded by the Functional Solutions Analysis (FSA) which has frequent mention of TSAS as an aircraft survivability solution for various phases of flight.

2) Combat Capabilities Document for Air Soldier Systems signed November 2011. PEO Soldier sponsored the CCD via the Air Soldier program. Tactile cueing is included as a combined visual, auditory and tactile display to maintain awareness especially in DVE. The CCD was funded as a milestone B for FY 2012. With significant reductions to the FY 12 budget, the TSAS did not make the FY 12 funding cut. TSAS remains eligible for FY13 and beyond with the now signed requirement from the Air Warrior office.

1.4 Associated Doctrine Development

The requirements developed by the US Army (FNA, FSA and ICD) have been a 5 year effort culminated by the ICD signing Oct FY 12. As each document was approved, it was forwarded to the Marine Corps requirements personnel interested in the advancement of TSAS.

1.4.1 Concept of Employment (CONEMP)

The Concept of Employment/Operations for TSAS was determined by a joint working group of Special Operations Forces (SOF) operators from Air Force Special Operations Command (AFSOC) and the Army Special Operations Aviation Regiment (SOAR) together with researchers from the Navy Aeromedical Research Laboratory. The following paragraph describing the Concept of Operations (CONOPS) is from the joint working group.

Helicopter aircrews require a system that provides intuitive tactile cuing for spatial orientation during periods of limited visibility or obscuration of ground references during all phases of flight, but most importantly during the landing phase. This will include hover cues, terrain following/terrain avoidance (TF/TA) climb, dive, steering cues, and threat warning cues. The system should echo the guidance cues provided by the existing aircraft visual instruments, however it is not intended to replace visual stimuli. When used with threat warning system, the tactile cuing system will provide cuing as to the relative location of threats identified by the on board Electronic Warfare (EW) suite. Improved cuing will provide faster reaction times during threat engagements. The system will be set up to provide hover cues automatically below a selected airspeed. In this configuration, the system will provide indications of lateral, longitudinal, and vertical deviations during a hover. The hover configuration frees the crew to operate other aircraft systems rather than visually monitoring aircraft hover cues presented on heads-down displays. When incorporated in TF/TA operations, the tactile cuing system echoes the climb/dive command cues the crews receive on current instruments. The TF/TA configuration will allow the crew to focus on other tasks. When used with threat warning system, the tactile cuing system will provide cuing as to the relative location of threats identified by the on board Electronic Warfare (EW) suite. Additional applications for consideration as part of the spiral developmental effort include lateral steering, and flight director guidance. The tactile cuing system should be integrated with existing or future systems planned for crew/aircraft integration (i.e. Air Warrior (AW), Microclimatic Cooling Garment (MCG)). The tactile cuing system should at a minimum, provide the pilot at the flight controls, the ability to retain his position over the surface below, without visual reference.

1.4.2 Tactics, Technique and Procedure (TTPs)

Since the TSAS is a material solution to DVE issues, TF/TA, Targeting displays, etc. that have been addressed up to this date primarily by tightly trained TTPs it is anticipated that TTPs will become easier with an additional intuitive display. The TTPs used in conjunction with TSAS will be developed by each operational community and platform as they adopt the TSAS technology.

2 Project Performance

2.1 Project Management

Project management was provided by the U.S. Army Aeromedical Research Laboratory as per Appendix C.

2.2 Funding

CWP funding of 1.1 million was provided FY 08 through FY 11 in increments of 390 K, 380 K and 330 K. Over the same time period the two SBIR programs contribute 2,069 K for a total U.S. investment of 3,169. Details are in the below chart.

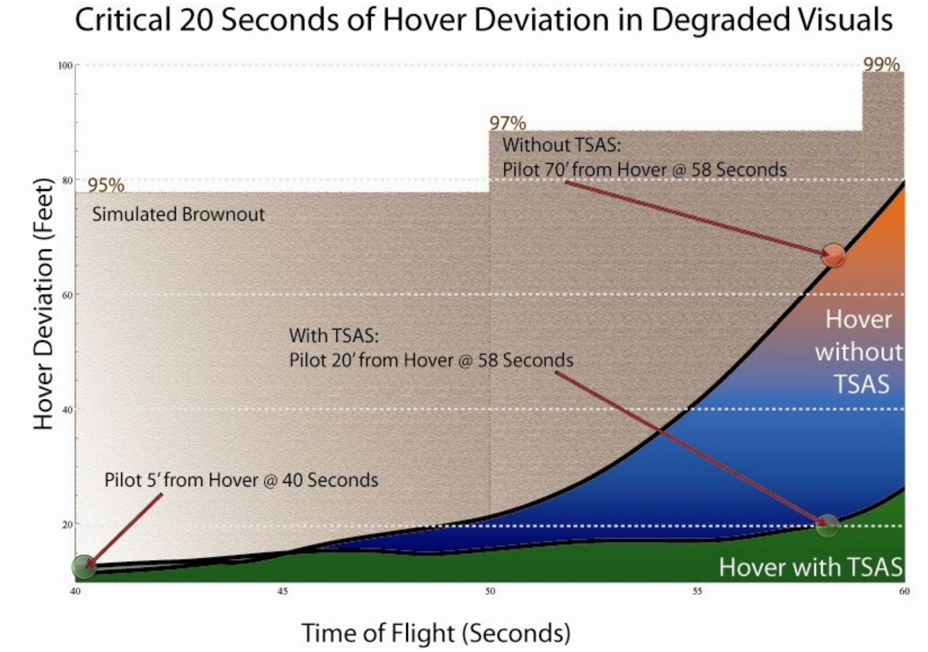
Funding Source	FY08 (if relevant)	FY09	FY10	FY11 (if relevant)	Category TOTAL
US Costs					
OUSD AT&L (CWP) PE 0603923D	390K	380K	330K		1,100K
Funding Source 1 PE SBIRs	469K	1,200K	400K		2,069K
US Financial Total Costs	859K	1580K	730K		3,169K
US Non-Financial Contributions					
Organization: Asset:					
Organization: Asset:					
US Total Contribution	859K	1580K	730K		3,169K
Partner Costs					
Partner Financial Costs (Canada)	245K	250K			495K
Partner Non-Financial Contributions	75K	80K			155K

(Canada)					
Country: Asset:					
Country: Asset:					
Partner Total Contribution	320K	330K			650K
Total Project Value	1,179K	1,910	730K		3,819K

3 Demonstrations

Throughout the program there were multiple demonstrations of the TSAS technology aided in part by the Defense Safety Oversight Council (DSOC) which provided funding to 1) build a portable TSAS demonstration unit to socialize the TSAS to key decision makers and 2) travel to several locations. The Bell 206 trainer which is common to Army (TH-67) and Navy (TH-57) was selected for the demonstration unit. Simulator demonstrations were provided to all three service groups AUSA (Association of the US Army), AFA (Air Force Association), Navy League; Navy Helicopter Association; Army Aviation Association of America; DSOC meetings and literally several hundred personnel in the Pentagon and other venues. Additionally simulator demonstrations have been provided to Army decision makers in the USAARL H-60 motion based simulator at Ft Rucker.

The hardware produced by CTI and EAI has been tested at Patuxent River in the Manned Flight Simulator (MFS) Sept 16/17 2010 and in-flight using a UH-1N February 2011. The flight testing in the MFS utilized 10 operational pilots performing hover in DVE with and without the benefit of TSAS.



The above graph illustrates the improvement of pilot performance when TSAS was available in simulated brownout conditions. The hover deviation in feet (lower value on ordinate scale is better) using TSAS remains low even as the brownout approaches 97 % degraded visual environment.

In-flight end-to-end testing of all TSAS components has been accomplished in the NACRA UH-IN and the USAARL H-60 aircraft. All components have received an Air Worthiness Release from the Army Aviation Engineering Duty Office.

Demonstrations have been instrumental in obtaining additional funding, requirement documents and support from the aviation community. Since TSAS uses a sensory system that has not been employed in the past to provide flight information, the demonstrations are the most effective technique to convince pilots and potential sponsors of the value of TSAS to enhance pilot performance, especially in DVE conditions.

4 Related Forums and Initiatives

The Defense Safety Oversight Council provided funding FY10/11 to promote the awareness and acceptance of TSAS as a tool to reduce the incidence of DVE related mishaps. Currently there are no active programs to develop and advance the use of tactile cueing in the aviation community.

5 Future Plans and Transition

There are several avenues that will be pursued to maintain the materiel progress and momentum that the CWP has provided via the TSAS program.

1) Requirements:

   a) The data that drives the requirements process in aviation safety is primarily related to loss of platforms and lives. The Army Combat Readiness Center/Safety Center will be conducting a review of the past 20 years of Class A mishaps specifically to determine whether each mishap could have prevented with TSAS. This data will continue to drive the requirements process.

   b) The ICD and CDD documents signed in FY 2012 provided requirements for TSAS but not funding. The typical length of time between the signing of an ICD and follow-on CDD with a Milestone B decision with funding is approximately four years. In the short term, effort will be focused on using the Class A mishap data to influence the CDD funding for FY13.

2) Funding:

   a) A phase II Supplemental will be submitted to obtain follow-on funding for one or both of the phase II companies that have been advancing the TSAS technology.

   b) Armed with the new requirements signed in FY12, a proposal will be submitted to the JCTD process. Past proposals to the JTCD were not accepted due to the absence of formal requirements.

   c) The TSAS technology associated with the tactors and garments will continue to move forward based on two recently granted phase II SBIRs: 1) tactile feedback balance platforms and 2) tactile cueing for dismounted soldiers. These two programs will bring flip chip technology to garment systems permitting advanced distributed systems resulting in greater ruggedness and lighter, more simplified systems.

3) Foreign Opportunities:

   a) The Australian Army developed a keen interest in TSAS with the arrival of an Australian liaison officer who had extensive special operations experience. Following an Aug 2010 TSAS demonstration to an Australian flag officer the Australians requested loan of a TSAS system for evaluation summer of 2011. Following an operational mishap the test program was placed on hold.

   b) The Canadian partner in the CWP has not been able to secure funding for DT/OT. The advantage of foreign country adoptation and implementation of TSAS is the rapidity with which a country having a smaller acquisition force can bring online a new technology. This is one of the areas in which CWP can provide a service to the US by providing more rapid transitions.

4) Signature Mishaps:

Occasionally there are aviation mishaps that become highly visible due to loss of significant number of personnel or to mission failure (e.g. Iran Hostage rescue failure 1979). It is important to be ready with TSAS as a solution when public interest is available to drive forward an immediate solution. The availability of recently signed requirements will assist should such a mishap become available.

5) Civilian Applications:

The civilian companies performing aeromedical evacuation and transportation of patients by helicopters have experienced a high rate of mishaps and scrutiny from the FAA to improve their safety record. The development of a civilian system may provide a faster route to availability of a Commercial-Off-The-Shelf (COTS) system that will assist the military acceptance of TSAS technology.

TRANSITION:

The initial transition plan as outlined in the CWP TSAS 2008 proposal included Special Operations and the U. S. Marine Corps in addition to the Canadian partner as the first recipients to implement the TSAS technology. The Marine Corps provided significant funding towards the deliverables but will not be able to progress with TSAS until they develop requirements. The Canadian partner has evaluated the TSAS product but does not have either funding or a current requirement to transition TSAS. Special Operations and the US Army are the only groups with current requirements permitting transition.

Transition is currently planned along 2 lines:

1) Army Special Operations – Recent demonstrations to USASOAC (BG Mangum, U.S. Army Special Operations Aviation Command), Technical Applications Program Office (TAPO) and members of Special Operations Aviation Regiment (SOAR) have resulted in a request to place TSAS in the SOAR assets for evaluation. The TAPO plans to include TSAS in FY 13 assessment of competing DVE technologies.

2) U.S. Army – The Army has recently signed two requirements documents (ICD and CCD) that include TSAS. In FY 12 the Army has initiated a five year 200 Mill program to evaluate and procure technologies to address DVE. The Army goal in FY 12 and FY 13 is to identify the best solutions to be included in the suite of technologies to solve DVE. TSAS will be promoted as the most advanced and cost effective solution.

6 Summary

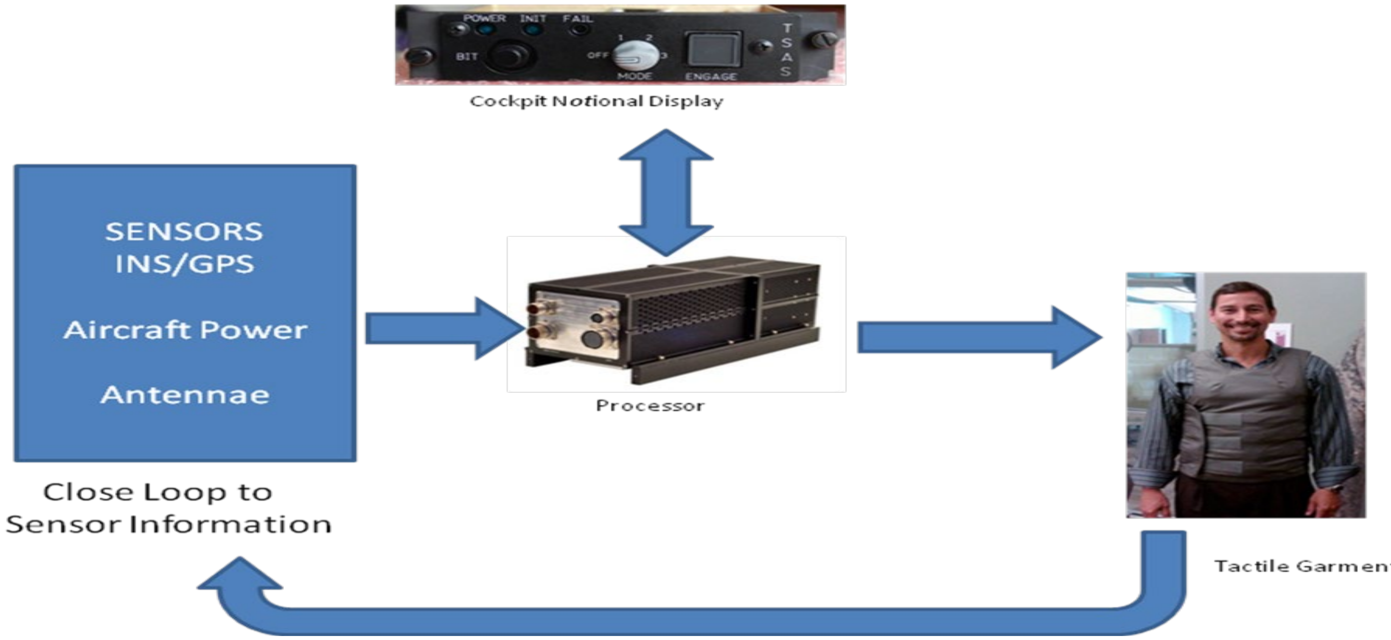
1) The CWP has provided the financial support to move the TSAS product forward to the point that military organizations can use TSAS for more advanced testing including DT/OT.

2) Equally important the CWP staff through DoD networking made it possible to leverage funding from the DSOC to provide briefs and demonstrations to decision makers that has in large part resulted in two FY 12 U.S. Army requirements: 1) the ICD for Aircraft Survivability including DVE and 2) the CDD for Air Soldier Systems. These acquisition requirements documents will facilitate additional development and adaptation of TSAS technology.

3) There are multiple paths forward outlined in Future Plans, one or more of which will continue to push tactile cueing into the cockpit.

APPENDIX A –ARCHITECTURE

The architecture of the TWAS solution is shown in the below diagram.



Sensor information from the aviation platform includes information from inertial sensors, GPS, Hostile Fire Indicator, Radar Altimeter, and virtually any item of interest that has an electronic signal. In legacy aircraft the minimum information (INS and GPS) is available from organic sensors in the processor.

The notional cockpit display in this latest generation TSAS permits the pilot to manually select mode of operation and whether the system is on or off.

The tactile garment may vary from a single belt to a combined 40 tactor vest with additional tactors in the seat cushion and seat belt harness depending on the application desired.

APPENDIX B - ACRONYMS

AED ……………………………………………………..Army Aviation Engineering Directorate

AFSOC ………………………………..……………..Air Force Special Operations Command

ARINC……………………………………...………………..Aeronautical Radio, Incorporated

ASIC…………………………………..…..…………...Applications Specific Integrated Circuit

AW…………………………………………………………………………………….Air Warrior

AWR…………………………………………………………...……… Air Worthiness Release

C-1, C-2……………………….……………designator for electromechanical tactors built by EAI

C4……………………………..……..Controlled Collapse Chip Connection also called Flip Chip

CCD……………………………………...…………..……. Combat Capabilities Document

CONOPS…………………………………………………….……….Concept of Operations

CONEMP………………………………………………………..…….Concept of Employment

COTS…………………………………...………………………...Commercial Off The Shelf

CRADA/MTA...Cooperative Research & Development Agreement/Material Transfer Agreement

CRC/SC ………………………………..……………..….Combat Readiness Center/Safety Center

CRD……………………………………………………..….Concepts & Requirements Directorate

CTI ……………………………………….…………………….. Chesapeake Technologies Inc.

CWP…………………………………………………………..…….Coalition Warfare Program

DCIEM …………………………...……..Defence and Civil Institute of Environmental Medicine

DCS………………………………………………………………………Deputy Chief of Staff

DoD……………………………………………………………….……..Department of Defense

DND ……………………..……...……………………………Department of National Defence

DRDC ……………………...……………………Defence Research and Development Canada

DSOC……………………………………………………….…….Defense Safety Oversight Council

DT/OT…………………………………………….……Developmental Testing/Operational Testing

DVE……………………………………………………………….Degraded Visual Environments

EAI……………………………………………………………………..Engineering Acoustics Inc.

EGI…………………………………………………………………………Embedded GPS/INS

EMI……………………………………………………………........Electro-Magnetic Interference

FSA ………………………………………………………………Functional Solutions Analysis

GPS…………………………………………….…………………Global Positioning System

ICD………………………………………………….…………Initial Capabilities Document

EMR………………………………………………….………..designator for a tactor made by EAI

EW……………………………………………………………….………Electronic Warfare

INS ………………………………………………………………….Inertial Navigation System

JCTD………………………………...……………Joint Concepts Technology Demonstration

JORD ………………………………………………Joint Operational Requirements Document

MCG……………………………………..…………………..Microclimate Cooling Garment

MFS…………………………………………………..………..Manned flight Simulator

NACRA……………………….……Naval Aviation Community for Rotorcraft Advancement

NASA ……..……………………………………..National Aeronautics and Space Administration

NAVAIR …………………………………………………...Naval Air Systems Command

NRC ……………………………………………………….…. National Research Council

SAR ……………………………………………………………….…Search and Rescue

SBIR ………………………………………………………Small Business Innovative Research

SOAR……………………….……………………Special Operations Aviation Regiment

SOF…………………………………………………………….….Special Operations Forces

SOCOM ……………………………………….…………..Special Operations Command

TAPO ……………………………………………Technical Applications Program Office

TF/TA………………………………………………Terrain Following/Terrain Awareness

TPA ……………………………………………..……..Technical Report Agreement

TTP………………………………………………………..Tactics, Techniques & Procedures

TSAS ....Tactile Situation Awareness System

USAARL …………………………………………U.S. Army Aeromedical Research Laboratory

USASOAC……………………………...….U.S. Army Special Operations Aviation Command

APPENDIX C- POINTS OF CONTACT

PROJECT MANAGEMENT (Primary):
NAME: Angus Rupert
TITLE: Research Scientist
COMMAND: USAARL
ADDRESS: Bldg 5901 Ft Rucker AL 36362
PHONE: 334 255 6965
FAX: 344 255 6993

PROJECT MANAGEMENT (Alternate):
NAME: Art Estrada
TITLE: Division Director WHD
COMMAND: USAARL
ADDRESS: Bldg 5901 Ft Rucker AL 36362
PHONE: 334 255 6928
FAX: 344 255 6993

FINANCIAL MANAGEMENT (Primary; add alternates as necessary):
NAME: Cynthia Lee
TITLE: Comptroller
COMMAND: USAARL
ADDRESS: Bldg 5901 Ft Rucker, AL 36362
PHONE: 334 255 6842 DSN 55
FAX: 334 255 6788 FAX

CONTRACTING MANAGEMENT (Primary; add alternates as necessary):
NAME: Susan Wells
TITLE: Contracts
COMMAND: USAARL
ADDRESS: Bldg 5901 Ft Rucker, AL 36362
PHONE: 334 255 6903
FAX: