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A brief history of the NPS Field Experimentation program: Spanning STAN, TNT and JIFX

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A BRIEF HISTORY OF THE NPS FIELD EXPERIMENTATION PROGRAM: SPANNING STAN, TNT, AND JIFX

by

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14. ABSTRACT
The NPS Field Experimentation Program was initiated in FY02 to provide an opportunity for NPS faculty and students to evaluate new technologies from their research in a field environment. These efforts were continued and integrated to create a formal decade long cooperative field experimental effort with USSOCOM (S&T/J9 and SORDAC) that began in FY03 as STAN (Surveillance and Targeting Acquisition Network) and culminated as TNT (Tactical Network Topology) in 2013. After TNT, sponsorship of NPS FX transitioned to OSD (AT&L) and the Department of Homeland Security (DHS). The NPS Joint Interagency Field Experimentation (JIFX) program exists today to support the S&T needs of all of the COCOMs, interagency, and first responders. This technical report serves to briefly document the history of the NPS FX program from STAN through current day JIFX. This document reflects the opinions of the author and does not represent the official policy or position of the Naval Postgraduate School, the United States Navy, or any other government organization.

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LIST OF ACRONYMS AND ABBREVIATIONS

APAFR	Avon Park Air Force Range
AFRL	Air Force Research Lab
ARL	Army Research Lab
ARM	Atmospheric Radiation Measurement
ARSENL	Advanced Robotics System Engineering Lab
ART/TSOA	Adaptive Red Team/ Technical Support Operational Activity
ASA(ALT)	Assistant Secretary of the Army, Acquisition, Logistics & Technology
C2	Command and Control
C4ISR	Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance
CA	Camp Atterbury (or California)
CAP	Civil Air Patrol
CAANG	California Army National Guard
CAVR	Center for Autonomous Vehicle Research
CD	Camp Dawson
CDTEMS	Center for Defense Technology and Education for the Military Services
CENETIX	Center for Network Experimentation and Innovation
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
COCOM	Combatant Command
CONOPS	Concept of Operations
COTS	Commercial Off the Shelf
CR	Camp Roberts
CRUSER	Consortium for Unmanned Systems Education and Research
DA	Defense Analysis Department
DARAO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DHS	Department of Homeland Security
FHL	Fort Hunter-Liggett
FEMA	Federal Emergency Management Agency
FEPSO	Field Experimentation Program for Special Operations
FX	Field Experimentation
GCS	Ground Control Station
GO	Governmental Organization
GOTS	Government Off the Shelf
GSE	Ground Support Equipment
GTRI	Georgia Tech Research Institute
HADR	Humanitarian Assistance and Disaster Response
JIEDDO	Joint Improvised Explosive Device Defeat Organization

JIFX	Joint Interagency Field Experimentation
JTCITS	Joint Tactical C4I Transceiver System
LLNL	Lawrence Livermore National Laboratory
LRV	Light Reconnaissance Vehicle
MAI	Mobile Access Infrastructure
MEU	Marine Expeditionary Unit
MIO	Maritime Interdiction Operations
MISSLE	Multi Institutional Semi-Structured Learning Environment
MOUT	Military Operations on Urban Terrain
NAVAIR	Naval Air Systems Command
NAWCWD	Naval Air Warfare Center Weapons Division (Point Mugu, CA)
NDU	National Defense University
NGO	Non-Governmental Organization
NPS	Naval Postgraduate School
NSW	Naval Special Warfare Command
NSWCCD	Naval Surface Warfare Center, Carderock Division, MD
NRL	Naval Research Lab
OFDM	Orthogonal Frequency Division Multiplexing
OFT	Office of Force Transformation
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
OSD (AT&L)	Undersecretary of Defense for Acquisition, Technology, and Logistics
OSD (HD)	Under Secretary of Defense for Homeland Defense
OSD (JOS)	Joint Operations Support under OSD(AT&L)
RELIEF	Research and Experimentation for Local and International Emergency and First Responders
RISTA	Reconnaissance Infrared Surveillance Target Acquisition
ROVER	Remotely Operated Video Enhanced Receiver
ROZ	Restricted Operating Zone
SBIR	Small Business Innovative Research
SBT	Special Boat Team
S&T	Science & Technology
SIPRNET	Secure Internet Protocol Router Network
SOAL	Special Operations Acquisition & Logistics
SOKF	Special Operations Knowledge and Futures
SORDAC	Special Operations Research, Development and Acquisition Center
STAN	Surveillance and Target Acquisition Network
STAR-TIDES	Sustainable Technologies Accelerated Research-Transportable Infrastructures for Development and Emergency Support
SWARM	Smart Warfighting Array of Reconfigurable Modules
TCS	Tactical Control System
TOC	Tactical (or Technical) Operations Center
TNT	Tactical Network Topology (later Tactical Network Testbed)
TSA	Technical Support Agreement

TUAS	Tactical Unmanned Aerial Systems (TUAS)
UAV	Unmanned Aerial Vehicle/Unmanned Autonomous Vehicle
UAS	Unmanned Aircraft System(s)
UGV	Unmanned Ground Vehicle
UMC	Unique Mission Cell
USSOCOM	US Special Operations Command
USV	Unmanned Surface Vehicle
UTC	Urban Training Center
UUV	Unmanned Underwater Vehicle
UxS	Generic for unmanned “ground, underwater, surface, air, etc.” system
WTI	Weapons and Tactics Instructor Course

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The comprehensive history of NPS Field Experimentation (FX) truly resides in the memory and actions of those that created, participated, nurtured, and managed the program from 2002 to present. This brief history is an attempt to record the "wave tops" of their notable efforts and achievements. I sincerely thank Dr. Dave Netzer, Dr. Alex Bordetsky, Dr. Ray Buettner, and Mrs. Marianna Jones for their detailed review of the document and along with Mr. Erik Syvrud and Mr. John Klopfenstein, for their valued recollections and selfless contributions to the NPS FX program. I would also like to thank Mr. Bob Bluth and Mr. Ray Jackson for their help in writing the history of CIRPAS/McMillan Airfield and CAVR professors Vladimir Dobrokhodov and Kevin Jones for their contributions as well. Many people contributed photos taken over the years. The collages in the appendix are only a micro-snap shot in time of the many friendships, collaborations, technologies, and experiments conducted over this ten year period. Without the memorable photos from Dr. Kevin Jones, Mr. Eugene Bourakov, Mr. Aurellio Monarrez, Mr. Alan Williams (GTRI), and the NPS Public Affairs Office (PAO) this would be a boring document indeed. Statistics and words alone can never completely describe the value of the NPS FX program but they are an important piece in understanding the impact of the FX venue. Thanks go to the untiring efforts of Mrs. Marianna Jones, Mr. Tristan Allen, Ms. Nelly Turley, Ms. Brittany Boucher (USSOCOM), Mr. Brian Russie (USSOCOM), and all of the NPS FX interns for event coordination, management, and data recording. Lastly, it is important to recognize the NPS student-warrior Defense Analysis master's thesis students: LT Joseph Butner (USN), CWO2 Christopher Manuel (USA), Maj Haspard Murphy (USAF), and Maj Kenneth Paxton (USAF). Without their service, passion, drive, and determination, there would never have been an NPS FX program.

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EXECUTIVE SUMMARY

The Naval Postgraduate School (NPS) Field Experimentation (FX) program was initiated in 2002 by the NPS Dean of Research, Distinguished Professor Dr. Dave Netzer, to provide (1) an opportunity for NPS faculty and students to demonstrate and evaluate new technologies related to their research in an operational field environment and (2) provide the operational community the opportunity to explore and experiment with these technologies. The first FX related experiments began in FY02 and focused on the use of unmanned aerial vehicles (UAVs) to improve Naval Special Warfare (NSW) forces downed pilot rescue capabilities. This novel project fostered the creation of a diverse network of academic researchers, military students, industry, and government participants focused on creating and evaluating emerging technologies in an operational context. It also set the precedent for subsequent NPS field experimentation.

In January 2003, the NPS FX efforts were continued and integrated into a formalized cooperative effort with U. S. Special Operations Command (USSOCOM) Science & Technology (S&T), and the J9 Special Operations Knowledge & Futures (SOKF) divisions. This cooperative was originally known as the Surveillance and Target Acquisition Network (STAN), and was renamed Tactical Network Topology (TNT) in late 2004. STAN/TNT originated out of an NPS Defense Analysis (DA) master's thesis[1] that focused on the "integration of a tetherless transmit/receive link[s] between soldiers, tactical vehicles, ground sensors, manned and unmanned platforms to push/pull secure voice, data, and video to USSOCOM components."[2]

Three NPS research centers played significant roles in the FX program. From the beginning, FX leveraged the unique research capabilities afforded by the Center for Autonomous Vehicle Research (CAVR) and the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS). The Center for Network Innovation and Experimentation (CENETIX) directly emerged out of the STAN/TNT programs.

As TNT evolved, non-governmental organizations, emergency personnel and first responders were included as FX focused on the science and technology (S&T) needs associated with Humanitarian Assistance and Disaster Response (HADR) operations. This new research thread was named RELIEF (Research and Experimentation for Local and International Emergency and First Responders) and was embedded into the TNT FX.

What initially started as a handful of NPS students and researchers, a few USSOCOM funded contractors, and $300K in research funding, eventually evolved into a $28M, decade long diversely funded multi-million dollar experimental knowledge crucible. That crucible, or multi-institutional semi-structured learning environment (MISSLE), forged an *informing system*

[1] CWO2 Christopher E. Manuel, USA, Maj H. R. Murphy, Jr., USAF, and Maj K. A. Paxton, USAF (2004). "The Surveillance And Target Acquisition Network (STAN)", NPS Masters Thesis (*restricted*), June 2004

[2] Manuel, Murphy and Paxton (2004) p. V

comprised of the joint services, federal, state and local governments, industry, academia – all focused on the operational S&T needs of the special operators. In its peak years, TNT hosted 750 participants completing 64 experiments (TNT 11-4), and 320 participants involved with 90 experiments (TNT 13-2).

Over the years, TNT experiments were conducted in several diverse venues. These settings included NPS laboratories on campus, the NPS Beach Laboratory and Monterey Bay, CIRPAS at the Marina Airport, the U.S. Army Post Fort Ord Military Operations on Urban Terrain (MOUT), the NPS-CIRPAS UAV test facility at McMillan Airfield, Camp Roberts California Army National Guard Base in Paso Robles, and maritime interdiction operations (MIO) experiments in the San Francisco Bay. As the cooperative matured and expanded, other experimental venues were added outside of California such as Avon Park Air Force Range in Florida, Camp Dawson in West Virginia, Camp Atterbury and the Muscatatuck Urban Training Center (UTC) in Indiana, and MIO experiments at locations throughout Europe in support of NATO allies.

TNT came to a close in 2013, marking the end of a decade long USSOCOM-NPS field experimentation cooperative relationship. Though the SOCOM-NPS cooperative era had come to a close, the TNT FX informing system model proved to be a viable, sought after means of exploring technology in a field setting. NPS FX continues today under new sponsors and is now known as Joint Inter-Agency Field Experimentation (JIFX). JIFX is funded by the office of the Under Secretary of Defense, for Acquisition, Technology and Logistics, OSD(AT&L), Joint Operations Support (JOS) and the Department of Homeland Security (DHS). Rather than solely focused on the S&T needs of one combatant commander (COCOM), JIFX addresses the S&T gaps of all COCOMS, interagency organizations, as well as federal, local, and international first responders.

This paper serves to provide an historic overview of the NPS FX program, documenting its origins from STAN, TNT, and to present day JIFX.

NPS FIELD EXPERIMENTATION (FX): THE EARLY DAYS

The NPS Field Experimentation (FX) Program was initiated in 2002 by the NPS Dean of Research, Distinguished Professor Dr. Dave Netzer[3] (*see Fig. 1*) to provide (1) an opportunity for NPS faculty and students to demonstrate and evaluate new technologies related to their research in an operational field environment and (2) provide the operational community the opportunity to utilize and experiment with these technologies. In coordination with the Associate Provost for Academic Affairs, Ms. Julie Filizetti, a proposal for field research was submitted to California 20th District Congressman Samuel Farr's office for Center for Defense Technology and Education for the Military Services (CDTEMS) congressional support. CDTEMS funding accounted for 22% ($6.34M) of NPS FX support from fiscal years (FY) 2002-2010.

Figure 1. Dr. Dave Netzer

The first FX related experiments in FY02 focused on the use of unmanned aerial vehicles (UAVs) to improve Naval Special Warfare (NSW) forces downed pilot rescue capabilities (*see Fig. 2*). These field experiments were led by Defense Analysis (DA) Master's student LT Joseph C. Butner, USN, and documented in his thesis[4] titled *Experimental Analysis of Integration of Tactical Unmanned Aerial Vehicles and Naval Special Warfare Operations Forces.* "Josh's" thesis advisors were Dr. Dave Netzer and Dr. Phil Depoy, Director of the NPS Wayne E. Meyer Institute of Systems Engineering. This initial thesis focused on two parts. First, it created a diverse network of academic researchers, military students, industry, and government participants capable of evaluating emerging technologies in an operational yet analytical environment that could be repeated by follow-on students and researchers. Second, it focused on the analysis of the integration of small UAS during a specific NSW downed pilot mission scenario.

Figure 2. GCS for Smart Warfighting Array of Reconfigurable Modules (SWARM) program UAS from Naval Surface Warfare Center, Carderock Division (NSWCCD) at McMillan Airfield, Camp Roberts, CA NG Base (Source: Figure 3, Butner thesis (2002) p. 19.)

[3] http://faculty.nps.edu/vitae/cgi-bin/vita.cgi?p=display_vita&id=1023567648

[4] Butner IV, J. C. (2002). *Experimental Analysis of Integration of Tactical Unmanned Aerial Vehicles and Naval Special Warfare Operations Forces*, NPS Masters Thesis, December 2002. Last accessed 6 June 2014 at http://www.dtic.mil/dtic/tr/fulltext/u2/a409922.pdf

Camp Roberts California Army National Guard (CAANG)[5] Base proved to be the ideal location for NPS FX research. Camp Roberts (*see Fig. 3*) was only two hours south of Monterey, and possessed ranges, restricted airspace, and a refurbished 3,500 foot improved airstrip operated since 1998 by the NPS Center for Independently Remotely Piloted Aircraft Studies (CIRPAS).

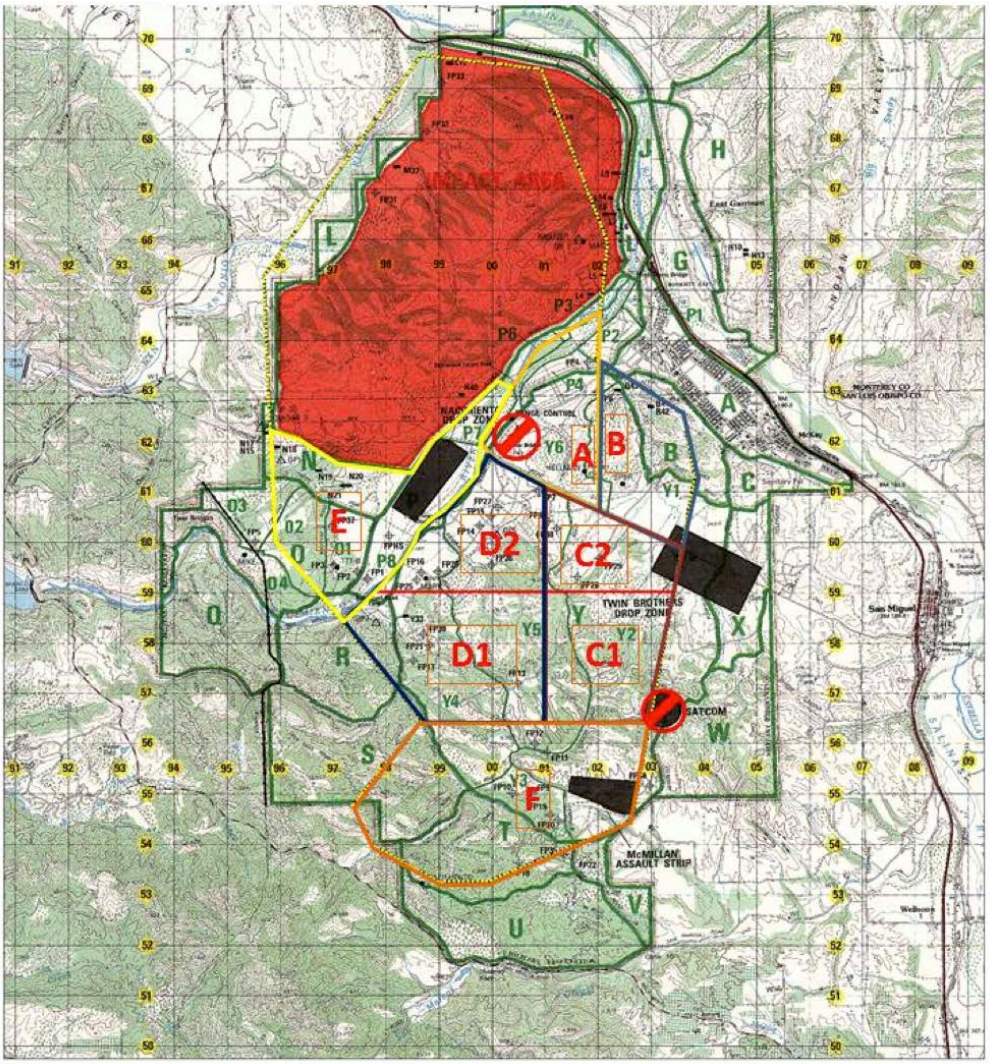

Figure 3. McMillan Airfield and Camp Roberts CA ANG Base range map showing aviation restricted operating zones (ROZ) @ 2013

By the end of 2002, NPS research in support of special operations began to take hold, thus setting the stage for a decade long cooperative research relationship between NPS, USSOCOM, CIRPAS, and Camp Roberts. A brief history of CIRPAS and McMillan Airfield follows.

[5] http://www.calguard.ca.gov/CR

STAN: SURVEILANCE AND TARGET ACQUISITION NETWORK

In January 2003, NPS FX was combined with another master's thesis to create a cooperative field experimentation effort with U. S. Special Operations Command (USSOCOM) Science & Technology (S&T) and J9 Knowledge & Futures (SOKF) divisions. This cooperative, originally known as the Surveillance and Target Acquisition Network (STAN), was named in memory of Chief Warrant Officer 2, Stanley Harriman, USA, who was killed by USAF AC-130 friendly fire in Afghanistan on March 2, 2002. STAN was conceived by DA Master's students CWO2 Christopher E. Manuel, USA, Maj Haspard R. Murphy, Jr., USAF, and Maj Kenneth A. Paxton, USAF, and documented in their 2004 restricted distribution thesis titled *"The Surveillance And Target Acquisition Network (STAN)."* This STAN thesis focused on the "integration of a tetherless transmit/receive link[s] between soldiers, tactical vehicles, ground sensors, manned and unmanned platforms to push/pull secure voice, data, and video to USSOCOM components" (p. V). Their thesis began as a joint interdisciplinary project between the NPS DA Department, chaired by Dr. Gordon McCormick, the Dean of Research, Dr. David Netzer, Dr. Alex Bordetsky, Information Sciences Department, and included several professors from multiple academic disciplines. STAN's initial experimental efforts focused on developing both the first remotely operated video enhanced receiver (ROVER) prototype *and* the associated surveillance and target acquisition network (STAN) necessary to link all relevant assets in the tactical environment (*see Fig. 4*). To accomplish this task, a multi-disciplinary team of NPS research faculty and over thirty thesis students was formed to generate ideas and solutions. The NPS team focused on the tactical network development and monitoring for each experiment. Military units and a contractor team were integrated with NPS to assist in determining requirements and producing prototypes for experimentation.

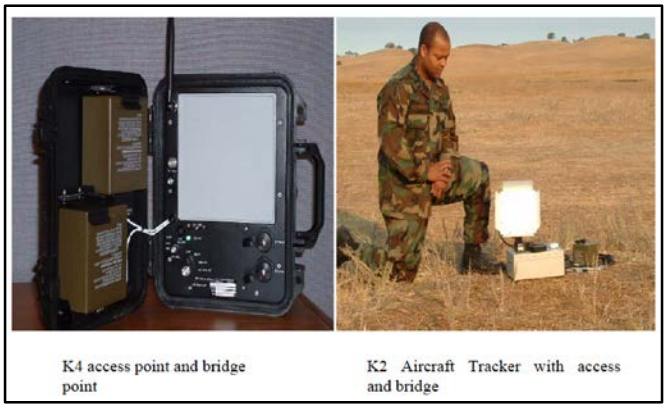

Figure 4. SNC/AKSI STAN Network Components, (source: Figure 3-2 , Manuel et al. thesis 2004, p. 36)

Seven STAN experiments were conducted from July 2003 to August 2004 at locations that included the Center for Independently Remotely Piloted Airship Studies (CIRPAS) at McMillan airfield, Camp Roberts CAANG base and the CIRPAS facility at Marina municipal airport (KOAR), the Military Operations on Urban Terrain (MOUT) facility at Fort Ord, CA, and Reno, NV. Other California locations included Fort Hunter Liggett, Lake San Antonio, Monterey Bay, and NPS (*see Table 1*).

Table 1. STAN dates and locations

Event	Date	Location(s)
STAN 1	Jun 03	Camp Roberts
STAN 2	Jul 03	Reno (NV) and CIRPAS Marina, Fort Ord MOUT (CA)
STAN 3	Sep 03	Camp Roberts
STAN 4	Oct 03	Camp Roberts
STAN 5	Feb 04	Camp Roberts, Lake San Antonio
STAN 6	May 04	Camp Roberts
STAN 7	Aug 04	Fort Ord MOUT, NPS, Monterey Bay, Camp Roberts

In addition to a few industry and government contractors, the Navy's Fleet Composite Squadron (VC) 6 supported all STAN and several TNT's with their Tern UAS until the unit was deactivated in August 2008. Tern (*see Fig. 5*) accommodated the integration of several ad hoc payloads in support of STAN objectives.

Figure 5. Tern UAV at McMillan Airfield

STAN proved to be very successful in linking academia, warfighters, and industry to quickly, and iteratively, address the technological needs and challenges of the special operator. The figure 6 post STAN 7 briefing slide lists a few of the experiment's accomplishments. Some of the notable technological achievements were (1) the establishment of a 100 (+) mile 802.16 wireless network linking NPS with Camp Roberts and Marina Airport, and providing an over the ocean link in Monterey Bay (*see Fig. 7*) and (2) the culmination of the Inter4 "Tacticomp" wireless mesh tactical network device for use with special operators. A good portion of the Tacticomp testing was conducted at the Fort Ord MOUT facility (*see Fig. 8*).

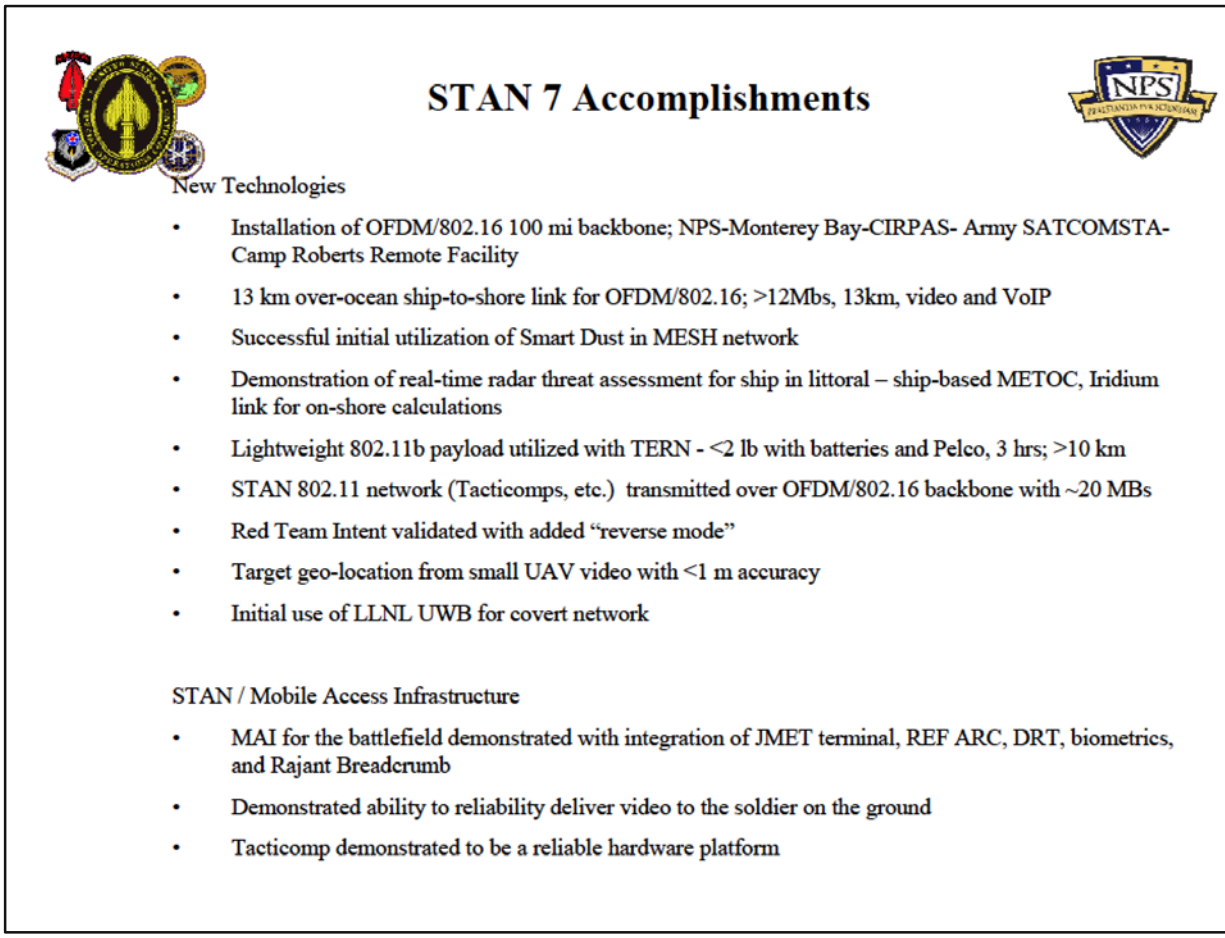

Figure 6. STAN 7 briefing slide showing list of accomplishments (NOV 2004)

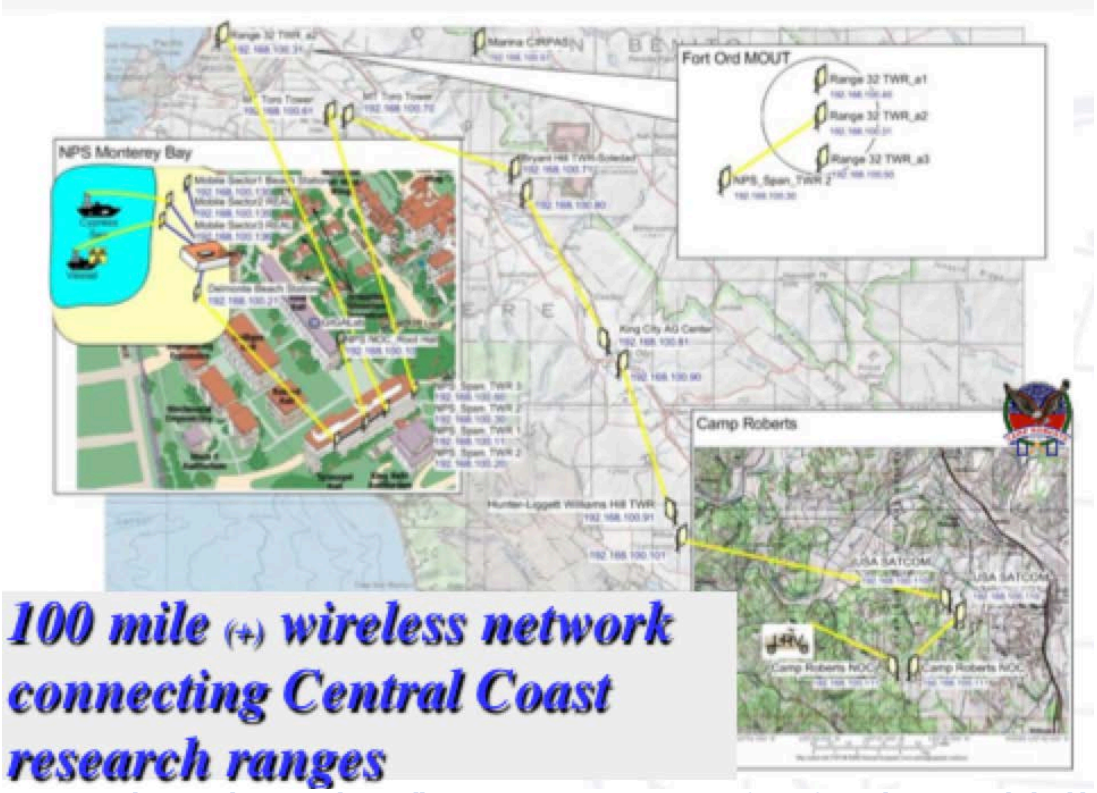

Figure 7. Map showing the 100 mile+ Redline Communications 802.16 (OFDM) wireless network backbone linking NPS, Camp Roberts and the Fort Ord MOUT facility.

Figure 8. NPS Nemesis networking RV at the Fort Ord MOUT facility, Marina, CA during Inter4 Tacticomp field tests 2004.

TNT: TACTICAL NETWORK TESTBED

The STAN experiments came to a close in August 2004, but FX continued under the name Tactical Network Topology (TNT)[6] and the first TNT (05-1) was held at Camp Roberts on November 2004. STAN ultimately transitioned into the USSOCOM programs Mobile Access Infrastructure (MAI) and Joint Tactical C4I Transceiver System (JTCITS). Junior officers Manuel, Murphy, and Paxton graduated NPS in December that same year. However, their thesis lived on and TNT continued advancing the knowledge, research, and organizational relationships developed from the successful STAN experiments. In August 2005, starting with TNT 05-4, USSOCOM SOKF-J9 took the lead from S&T and TNT began to explore a wider range of technologies.

CDTEMS funding began to gradually decline and ultimately ended in FY10. In 2005 NPS submitted a *Field Experimentation Program for Special Operations* (FEPSO) congressional funding proposal to Congressman Sam Farr's office requesting support for this now dedicated NPS-USSOCOM cooperative field experimentation venture. FEPSO funding was received in FY06 and continued through FY10, accounting for 22% of TNT funding. Additionally, OSD's Office of Force Transformation (OFT) funded some TNT research (FY06-FY08) that supported the *Stilletto/Wolfpack* projects and advanced antenna alignment research.

Figure 9. Dr. Alex Bordetsky

The transition from STAN to TNT also brought more involvement from the USSOCOM Component Commands. The goal was to focus on identifying key gaps and deficiencies that could be addressed by the application of advanced technology, particularly network communications, unmanned systems and net-centric applications. Promising technologies were typically evaluated—and their capabilities iterated – across several TNTs. Around this same time the NPS Information Sciences Department established the Center for Network Innovation and Experimentation (CENETIX)[7], directed by Dr. Alex Bordetsky (*see Fig. 9*). CENETIX emerged from the experimental knowledge gained from STAN's network research emphasis. CENETIX subsequently became the lead agent for integrating, testing, and managing all of the network related experiment activities.

Dr. Bordetsky also assumed the lead for directing TNT's Maritime interdiction operations (MIO) experiments (*see Fig. 10*) and biomedical related experimentation. By the end of STAN 7, the NPS Tactical Network Testbed had established an 802.16 RedLine broadband wireless network that connected NPS with Camp Roberts (100+ nm), CIRPAS Marina, Fort Ord, the NPS Beach Lab and the Monterey Bay (Fig. 7). Subsequent events would additionally link Fort Hunter Liggett,

[6] *In 2010 Tactical Network Topology (TNT) was renamed the tactical network testbed (TNT) which was more aligned with original STAN/early TNT intent.*

[7] http://cenetix.nps.edu/cenetix/

Lawrence Livermore National Laboratory (LLNL) and various other collaborating labs and commands.

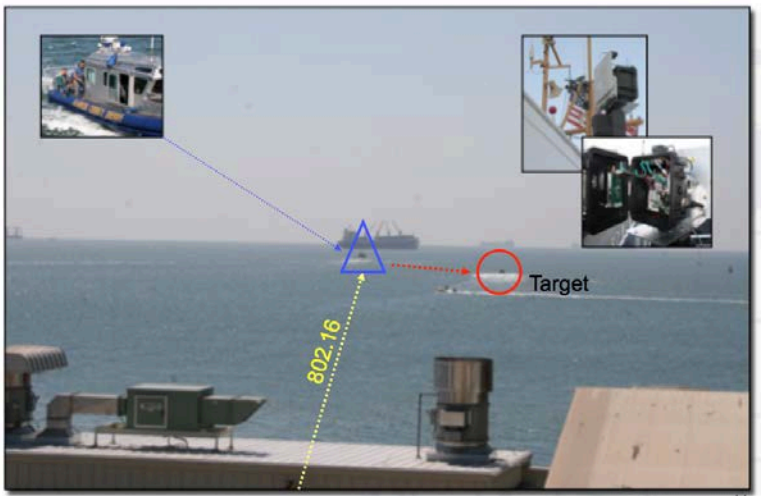

Figure 10. TNT MIO self-aligning antenna experiment San Francisco Bay

STAN's emphasis was the linking, via the network, of tactical operators with unmanned systems resources (i.e., imagery, communications, C2, sensor data, etc.). This emerging technical requirement placed a challenging demand on the immature wireless mesh technologies and associated data protocols of the time. The surveillance and targeting acquisition *network* and the TNT testbed both evolved out of the dynamic, iterative field-testing catalyzed by this operational requirement. As a result, numerous commercial off the shelf (COTS) networking technologies were tested and adapted in unique ways in order to assess their operational utility. As a result, desirable technologies improved, were filtered out, or best yet--emerged out of the TNT informing system. STAN/TNT evaluated all variants of the IEEE standard 802.11, ITT/Motorola mesh cards, and pre-IEEE 802.16 broadband technologies in the topographically demanding Camp Roberts environment. After several years of trials, adaptation, and vendor testing, Persistent System's Wave Relay OSI layer 2 mesh was adopted as the permanent air-ground wireless network for the Camp Roberts CENETIX testbed. This tactical local area network was connected with the Redline 802.16 network backhaul link. The network was critical to TNT operational testing and maintaining the network during each event eventually was tasked to SOCOM contractor Wintec Arrowmaker, Inc. The technical operations center (TOC) (*see Fig. 11*) was the hub for all FX operational control, network monitoring, and data collection efforts. Figure 12 depicts a typical TNT Wave Relay network setup.

Figure 11. TNT Technical Operations Center (TOC)

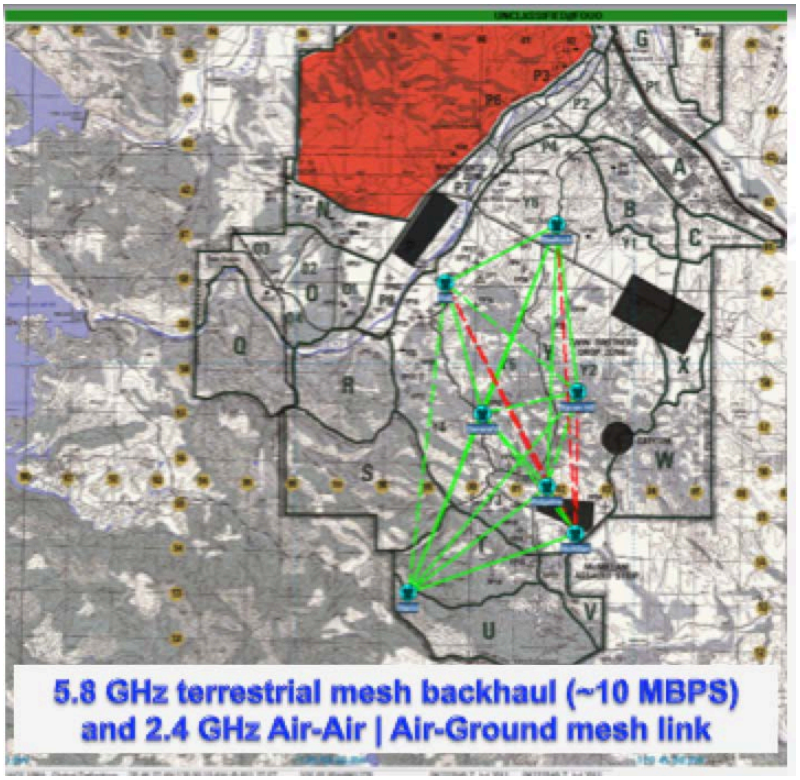

Figure 12.Typical TNT Persistent Systems Wave Relay air-ground mesh network setup

In the years following STAN, TNT branched out into several operationally diverse experimental venues. While Camp Roberts remained the predominant experimentation hub, TNT's were also held four times at Avon Park Air Force Range (APAFR), Florida and once at Muscatatuck Urban Training Center (UTC), Indiana. Other locations were often integrated with the Camp Roberts TNT event. These locations included: Camp Dawson and National Response Events in West Virginia, Camp Atterbury in Indiana, John C. Stennis Space Center in Mississippi, and Fort Eustis in Virginia. Additional California locations included Fort Ord (MOUT), CA, Marina Municipal Airport (KAOR), NPS and Monterey Bay, San Clemente Island, Fort Hunter-Liggett and Lake San Antonio. MIO experiments were conducted at Alameda Island, San Francisco Bay, Yerba Buena Island, New York and New Jersey Harbors, as well as various European locations (*see Table 2*).

Figure 13. GTRI JIEDDO and Sundial sustainable solar power experiments

Table 2. TNT events and locations

Event	Date	Location(s)
TNT 05-1	Nov 04	Camp Roberts (CR), Fort Ord, Monterey Bay (MRY Bay), NPS
TNT 05-2	Feb 05	Camp Roberts, Fort Ord, MRY Bay, NPS
TNT 05-3	May 05	Camp Roberts Fort Ord, MRY Bay, NPS
TNT 05-4	Aug/Sep 05	Camp Roberts
TNT 06-1	Nov 05	Camp Roberts, Alameda (MIO)
TNT 06-2	Feb/Mar 06	Camp Roberts, Alameda (MIO)
TNT 06-3	Jun 06	Camp Roberts Alameda (MIO)
TNT 06-4	Aug 06	SF Bay (MIO)
TNT 07-1	27 Oct – 2 Nov 06 29 Nov – 1 Dec 06	Camp Roberts San Francisco Bay, CA (SF Bay), (MIO)
TNT 07-2	24 Feb – 4 Mar 07 19 – 21 Mar 07	Camp Roberts, Fort Hunter Liggett (FHL) Yerba Buena Island, CA (MIO)
TNT 07-3	12-18 may 07 4-7 Jun 07	Camp Roberts, Fort Hunter Liggett, Camp Dawson, WV, Camp Atterbury, Yerba Buena Island (MIO)
TNT 07-4	17 – 24 Aug 07 10 – 13 Sep 07	Camp Roberts, Fort Hunter Liggett, Camp Dawson, Camp Atterbury Yerba Buena Island (MIO),
TNT 08-1	1 – 9 Nov 07	Camp Roberts, Camp Dawson, Camp Atterbury
TNT 08-2	4 – 6 Feb 08 23 – 29 Feb 08 3 – 7 Mar 08 10 -13 Mar 08	San Clemente Island, CA Camp Roberts, Camp Dawson, Camp Atterbury European component (MIO) SF Bay (MIO)
TNT 08-3	10 – 16 May 08	Camp Roberts, FHL, Camp Dawson, Camp Atterbury
TNT 08-4	16 – 22 Aug 08 8 -12 Sep 08	Camp Roberts, FHL, CD, Ctr for Ntl Response Events, WV, Camp Atterbury, MIO: NY/NJ Harbor & Hampton Roads, Fort Eustis, VA, Germany, Sweden
TNT 09-1	10- 21 Nov 08	Camp Roberts, Ctr for Ntl Response Events, WV, Camp Atterbury
TNT 09-2	21 – 27 Feb 09 22 – 27 Feb 09	Camp Roberts Camp Dawson
TNT 09-3	10 – 14 May 09 8 – 12 Jun 09	Camp Roberts Camp Atterbury
TNT 09-4	8 – 13 Aug 09	Camp Roberts
TNT 10-1	14 – 20 Nov	Camp Roberts
TNT 10-2	18 – 26 Feb 10	Avon Park AFR, FL, John C. Stennis Space Ctr, Mississippi
TNT 10-3	5 – 14 May 10	Camp Roberts (CBE: Concept Based Experiments)
TNT 10-4	3 – 13 Aug 10	Camp Roberts, FHL
TNT 11-1	9 – 19 Nov 10	Camp Roberts
TNT 11-2	22 – 26 Feb 11	Avon Park AFR
TNT 11-3	8 – 13 May	Camp Roberts
TNT 11-4	7 – 12 Aug 11	Camp Roberts
TNT 12-1	1 – 10 Nov 11	Camp Roberts
TNT 12-2	7 – 17 Feb 12	Avon Park AFR
TNT 12-3	30 Apr – 11 May 12	Camp Roberts
TNT 12-4	1- 9 Aug 2012	Camp Roberts
TNT 13-1	30 Oct – 8 Nov 12	Muscatatuck UTC, IN
TNT 13-2	26 Feb – 7 Mar 13	Avon Park AFR
TNT 13-3	4 – 13 Jun 13	Camp Roberts

Many internal organizational changes occurred at SOCOM over the years and management and oversight of TNT shifted from Special Operations Research, Development, and Acquisition Center (SORDAC)[8] S&T (Experimentation) to SOKF-J9 (Experimentation), back to S&T, and ultimately back to SORDAC S&T in 2011. A good portion of the USSOCOM mission based TNT experimentation over the years had focused on deployable force protection. This emphasis shifted to ARL's Unique Mission Cell (UMC) after the 2011 USSOCOM organizational restructuring and eventually became known as the Adaptive Red Team Technical Support Operational Activity (ART/TSOA)[9]. ART/TSOA is sponsored by OSD, funded by the Assistant Secretary of the Army for Acquisition, Logistics & Technology ASA(ALT), and executed by the UMC. ART/TSOA still routinely conducts operational experimentation at Camp Roberts.

Dr. Dave Netzer retired from NPS after 40 years of civil service in 2009. Dr. Raymond R. Buettner, Jr. became the NPS FX director in 2009 (TNT 09-2) until TNT ended in 2013. Table 3 highlights the key personnel changes and associated event dates.

Table 3. STAN/TNT Key Personnel and Dates

Events	Dates	USSOCOM Lead(s)	NPS FX Director
STAN 1 – TNT 05-3	Jul 2002 - May 2005	-SORDAC S&T, Exp. Lead: Mr. Erik Syvrud Mr. John Klopfenstein	Dr. Dave E. Netzer
TNT 05-4 – TNT 06-4	Aug 2005- Aug 2006	-SOKF J-9: LCDR Gordon A. "Gordo" Cross, USN -SOAL Advanced Tech. Directorate	*(Netzer as above)*
TNT 07-1 – TNT 08-4	Oct 2006 – Aug 2007	SOKF J-9: LCDR Dave "Chilly" Culpepper, USN LtCol Mark Brinkman, USMC *(TNT 07-1 only)*	*(Netzer as above)*
TNT 09-1 TNT 09-3	Nov 2008 – May 2009	LtCol Thomas "Bike" Beikirch, USMC	Dr. Raymond R. Buettner, Jr. (TNT 09-2, Feb 09)
TNT 09-4 – TNT 11-2	Aug 2009 – Feb 2011	S&T: Mr. William (Bill) Hellemn (S&T)	*(Buettner as above)*
TNT 11-3 – TNT 12-1	May 2011 – Nov 2011	(SORDAC S&T): Ms. Margaret M. McCaskey	*(Buettner as above)*
TNT 12-2 – TNT 13-3	Feb 2012 – Jun 2013	(SORDAC S&T): Mr. Gabriel Lifschitz	*(Buettner as above)*

Congressional earmarks provided ~51% of TNT's funding from FY02-FY13 and this helped off-set the costs associated with running the experimental venue four times per year. SOCOM augmented the CDTEMS, FEPSO, and Light Reconnaissance Vehicle (LRV) earmark funding with an additional 18%. Combined OSD (HD, OFT) and ARL funding also provided 13%, ARL 6%, and

[8] http://www.socom.mil/SORDAC/Pages/Default.aspx
[9] http://uniquemissioncell.org

the remaining 12% was supplied from various sources. Figure 14 provides the 11-year funding summary.

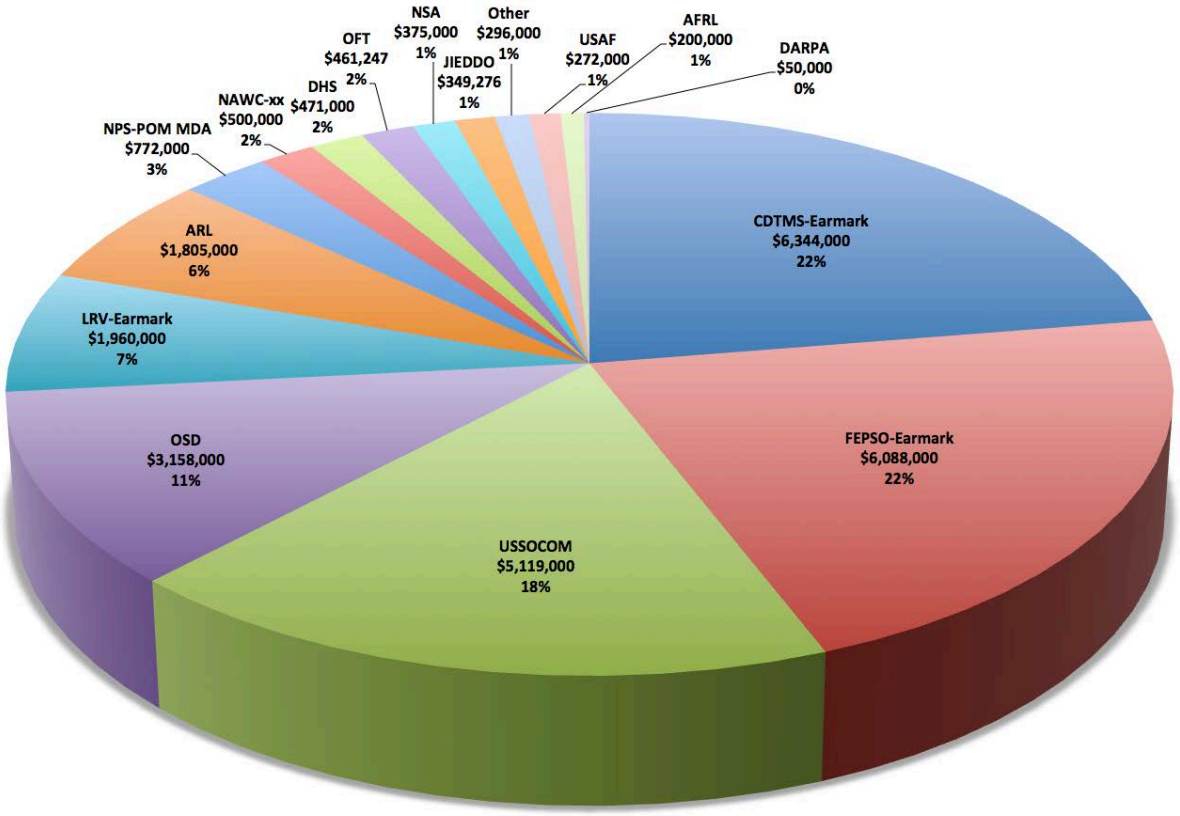

Figure 14. NPS FX Funding FY02-FY13

When the congressional adds ended in FY10, SOCOM TNT funding began to increase, though sporadically (Fig. 15). The Army Research Lab (ARL) and OSD also began providing additional funding to support TNT research activities.

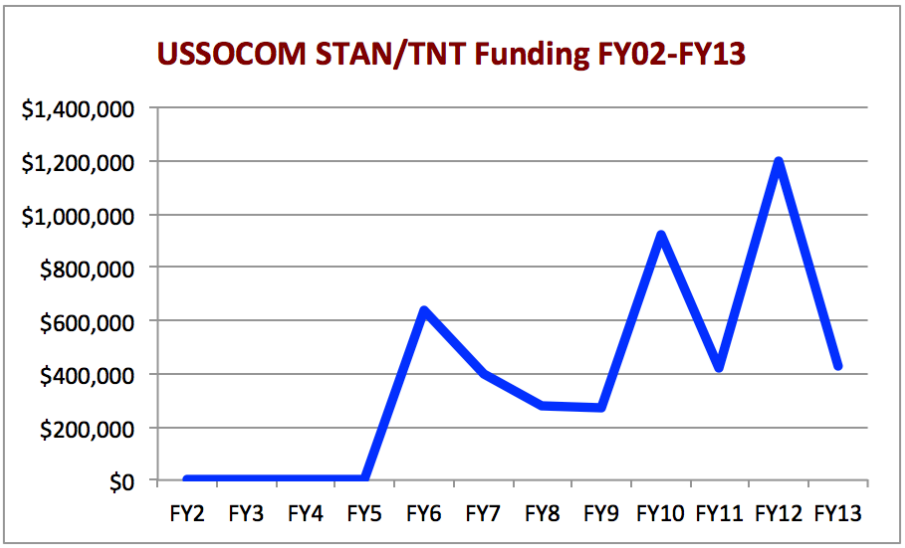

Figure 15. USSOCOM STAN/TNT Funding FY02-FY13

STAN/TNT was a unique, innovative and operationally driven research model that focused academia, government labs, and industry on the challenging tactical problems critical to the special operations warfighter. We take many of these technological advances for granted today, but such was not the case in the early TNT days. In addition to Rover improvements, numerous tactical broadband mesh networking and communications, unmanned air and ground systems, and various sensors started as field prototypes and accelerated their evolution through TNT participation (*see Appendix A*). The intent of the NPS FX program was always to foster the merger of "the operational art and commercial enterprise [in order to] work together through experimentation and feedback to produce what the operator requires."[10] The collaborative synergy that emerged from this informing system proved highly beneficial to all participants and was reflected in the resultant technologies and academic research work. Over 200 professional papers and student theses originated out of the TNT field research program (*see Appendix B*).

Approximately 1,100 TNT field experiments were conducted from 2007-2013 (*see Fig. 16*). Early STAN and TNT events (FY02-FY07) tended to be more narrowly focused on specific USSOCOM mission sets and did not involve a large number of industry participants performing individual experiments. Additionally, no detailed event statistics exist from these early events.

[10] Manuel, et al., p. 113

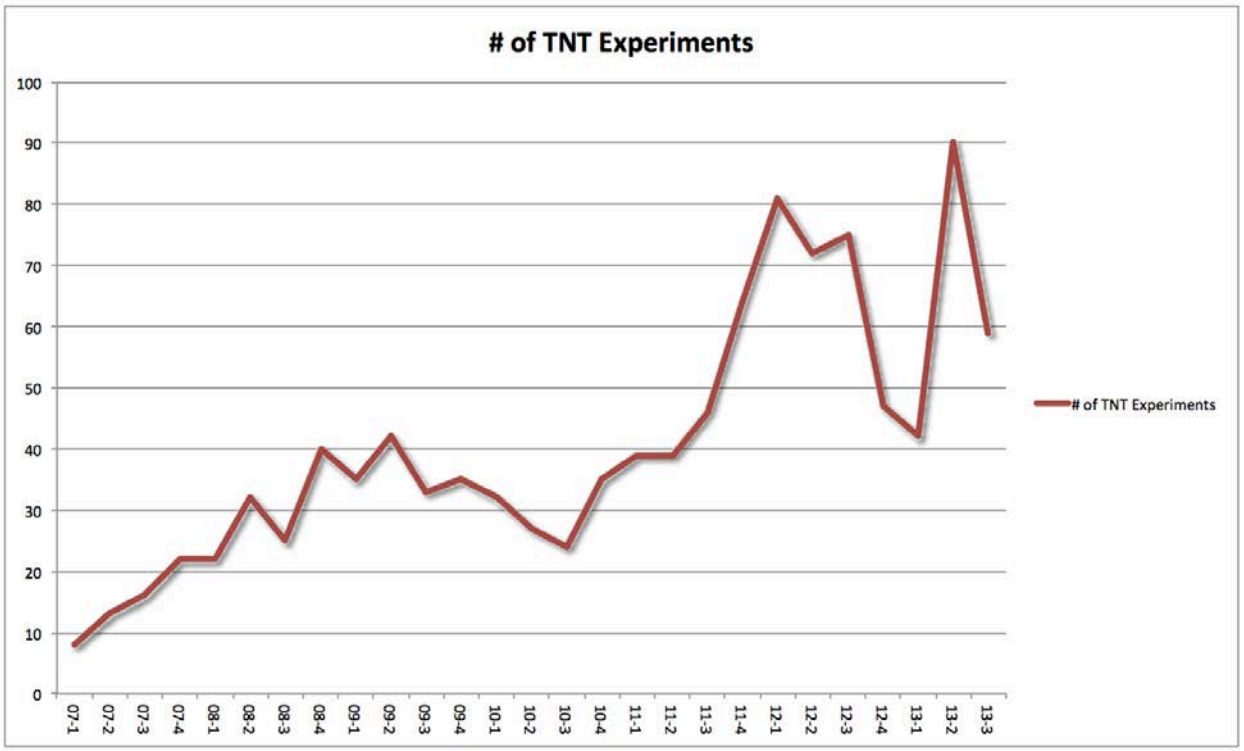

Figure 16. Number of TNT experiments (2007/Q4 - 2013/Q3)

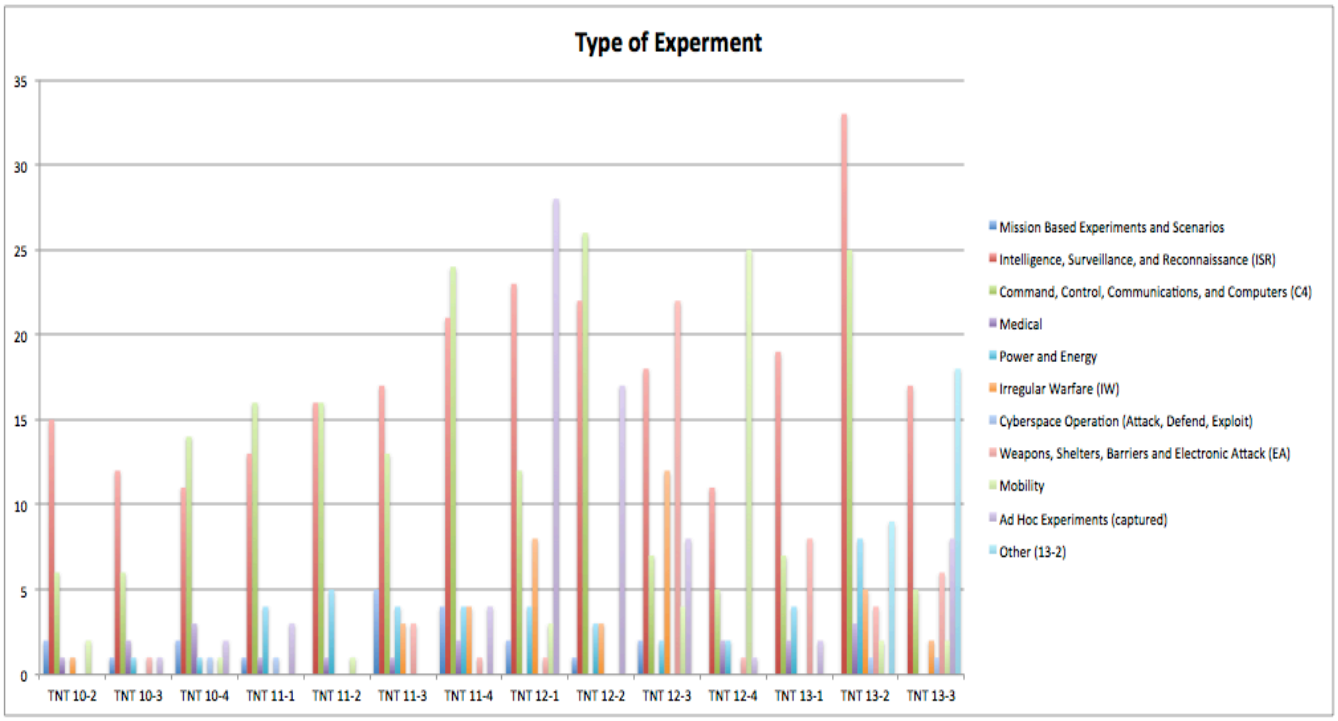

Figure 17. Breakdown of TNT experiment types (2011-2013/Q3)

Figure 17 shows the breakdown of the numbers and types of experimental focus areas conducted at TNT from FY10-FY13.

Manuel et al., in discussing the STAN conceptual framework and collaborative life cycle, foresaw the potential that STAN/TNT could eventually come to an end.

> "The operational art and commercial enterprise work together through experimentation and feedback to produce what the operator requires"…."This structure, applied to STAN, allows each component to take advantage of the expertise of the other components. NPS' joint military student body and its proximity to Silicon Valley provide a unique opportunity to conduct this type of project. CDTEMS provides funds to finance experimentation for educational purposes. This functions as a cost-sharing means for the military organization that provides funding to the companies. NPS provides the academic depth, supplying the problem-solving methodology and emerging technologies for experimentation, while commercial enterprise provides COTS items with modifications to use during experiments. The operational art then provides feedback to the commercial enterprise, which then fixes failures and prepares for the next experiment. This exchange continues until STAN is produced or is no longer wanted by any of the players involved."[11]

TNT 13-3 marked the end of a decade long, $28M NPS-USSOCOM cooperative field experimentation program. TNT has since transitioned into the Joint Interagency Field Experimentation (JIFX) program and is sponsored by OSD(AT&L) and DHS. JIFX continues to be scheduled quarterly and has now replaced TNT & RELIEF as the sole *interdisciplinary* NPS field experiment venue. For more FX information please visit www.nps.edu/FX

[11] Manuel et al., p. 113

RELIEF: RESEARCH AND EXPERIMENTATION FOR LOCAL AND INTERNATIONAL EMERGENCY FIRST RESPONDERS

In 2007, NPS and USSOCOM began examining dual-use capabilities for homeland security, stabilization, reconstruction, and humanitarian assistance/disaster relief (HADR). These new mission sets were integrated into the TNT field experiments starting with TNT 07-3. In 2009

Figure 18. RELIEF experiments at Camp Roberts

(TNT 09-2), Dr. Linton Wells II, then the Transformation Chair for the Center for Technology and National Security Policy (CTNSP) at National Defense University (NDU)[12] integrated NDU's humanitarian research into the TNT experiment venue. Dr. Wells was also the Coordinator for Sustainable Technologies Accelerated Research-Transportable Infrastructures for Development and Emergency Support (STAR-TIDES)[13]. As TNT began to integrate HADR missions and other federal agencies saw value in this focus area – agencies such as OSD, Homeland Defense (HD), Department for Homeland Security (DHS), Federal Emergency Management Agency (FEMA) – a new research thread was formalized and titled Research and Experimentation for Local and International Emergency and First Responders (RELIEF)[14].

Figure 19. Sundial sustainable solar and wind energy

RELIEF was created to address the most complex challenges identified by those most directly engaged in disaster relief. RELIEF brought together humanitarian practitioners, technology developers, federal civilians, and active duty military personnel for hands-on collaboration. Recent events were focused on crowd sourcing video techniques with civil air patrol (CAP) and FEMA incident support teams and were immediately put to action in response to hurricane Sandy. Since 2009, 13 RELIEF focused events were conducted in a multi-institutional field setting; providing a semi-structured learning environment capable of promoting collaboration and relationship building across an increasingly diverse governmental and civilian response network.

[12] http://www.ndu.edu
[13] http://star-tides.net
[14] For more information on RELIEF, see: www.nps.edu/fx, http://camproberts.org and http://star-tides.net/search/node/RELIEF

In 2013, the focus and intent of RELIEF was incorporated into the Joint Interagency Field Exploration (JIFX) program and RELIEF no longer exists as a stand-alone entity. Table 4 chronicles the RELIEF and JIFX related FX events.

Table 4. RELIEF and JIFX Experimentation from inception to present

Event	Dates	Remarks
TNT+ RELIEF 9-2	Feb 09	Relief #1. First NDU STAR-TIDES participation
TNT+ RELIEF 9-4	3-14 Aug 09	
TNT+ RELIEF 10-1	10-14 Nov 09	
RELIEF 10-3	May 10	
TNT+ RELIEF 10-4	3-6 Aug 10	
TNT+RELIEF 11-1	8-12 Nov 10	
TNT + RELIEF 11-3	2-13 May 11	
TNT+ RELIEF 11-4	2-5 Aug 11	
TNT + RELIEF 12-1	2-4 Nov 11	
JIFX 12-2	27 Feb-1 Mar 12	First JIFX
RELIEF 12-3	21-23 May 12	Lincoln Hall, NDU
JIFX + RELIEF 12-4	13-17 Aug 12	
JIFX + RELIEF 13-2	11-15 Feb 13	
RELIEF 13-3	6-9 May 13	
JIFX 13-4	5-8 Aug 13	
JIFX 14-1 (CR) JIFX 14-1 "Virtual"	CR Cancelled 19-20 Nov 2013	- U.S. Gov. Shut Down/Furloughs - Using Social Media for SA/Decision Support
JIFX 14-2	10-13 Feb 14	
JIFX 14-3	5-9 May 14	
JIFX 14-4	11-15 Aug 14	Camp Roberts & MIO Alameda Is., CA

JIFX: JOINT INTERAGENCY FIELD EXPERIMENTATION

STAN and ultimately TNT, forged a unique socio-technical ecosystem – industry, academia, the joint services, governmental and non-governmental agencies, first responders – all focused on the S&T needs of the warfighter. As TNT matured and acquired a variety of research sponsors and activities, the knowledge gained through participating in the venue expanded to benefit not only the sponsors but all of the participants as well. Dr. Raymond R. Buettner[15], Jr. became the FX director in February 2009. Recognizing that TNT had evolved into an *Informing System*, he aptly coined the TNT model a Multi-Institutional Semi-Structured Learning Environment (MISSLE)[16] where participants assumed the roles as both clients and informers. TNT and RELIEF were in essence socio-technical channels of communication that focused attention on client problems and informer capabilities but also created the environment for ad hoc experimentation and innovation.

Figure 20. Dr. Raymond Buettner, Jr.

Building on the highly successful SOCOM-NPS collaborative field research model, the Joint Interagency Field Exploration Program (JIFX)[17] was created in 2012 (JIFX 12-2). JIFX was conceived out of the desire to provide a field experimentation resource for *all* of the unified combatant commands and federal agencies with an informing system capable of addressing their unique S&T gaps. In addition, state, local and international emergency management, disaster response and humanitarian assistance organizations participate in JIFX helping to create an innovative cooperative learning environment. JIFX is sponsored by OSD's Joint Operations Support (JOS) Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics (AT&L) and DHS. This complex informing system served as a dynamic engine for NPS thesis students while enabling faculty to stay closely coupled to the joint warfighter.

[15] http://faculty.nps.edu/vitae/cgi-bin/vita.cgi?p=display_vita&id=1023567889
[16] Buettner, 2013
[17] See: www.nps.edu/fx

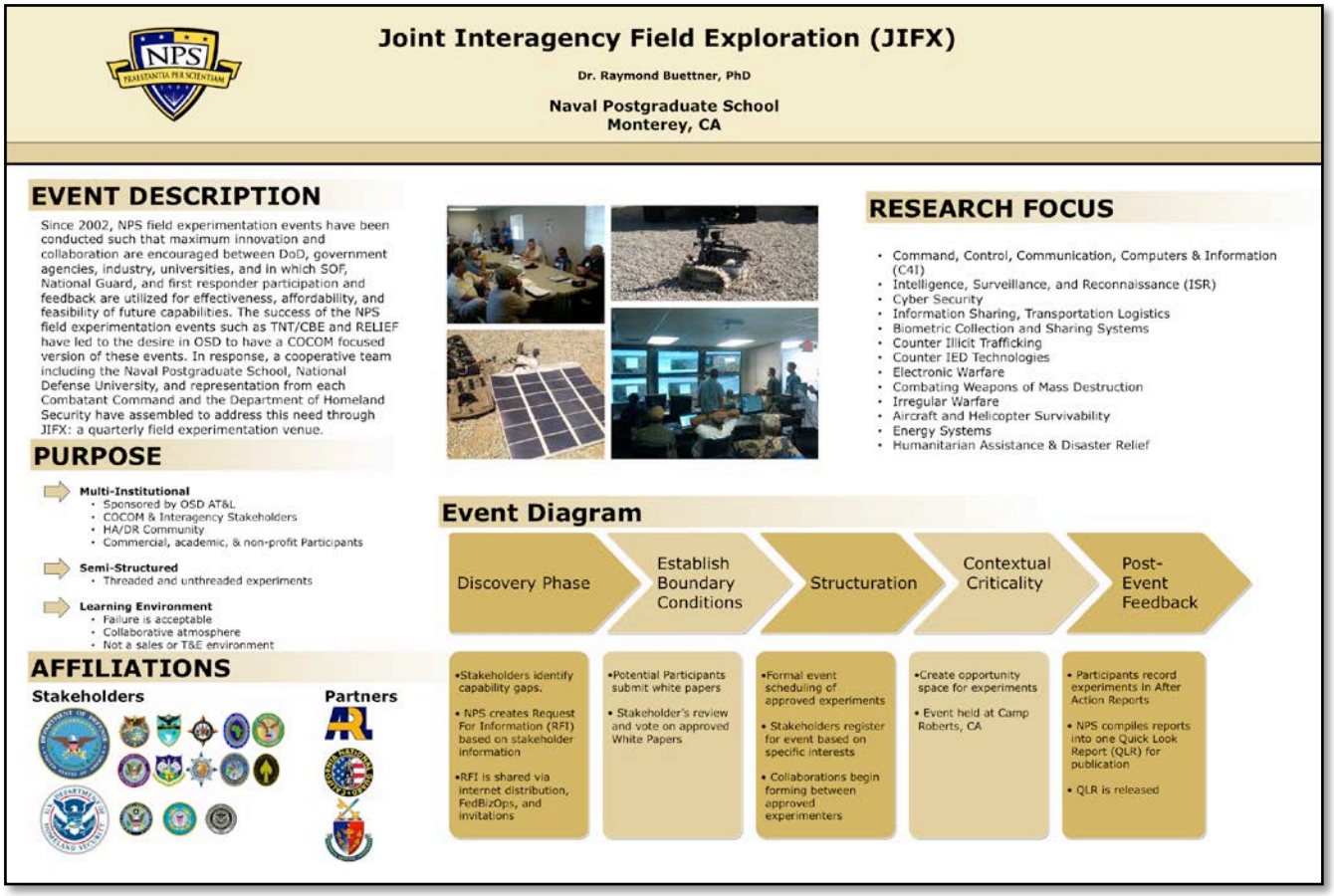

Figure 21. JIFX Overview

A. CIRPAS: CENTER FOR INTERDISCIPLINARY REMOTELY PILOTED AIRCRAFT STUDIES

1. Origins and History

The Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS)[18] is an NPS research center that operates manned and unmanned, instrumented research aircraft in support of the science community. CIRPAS also provides air vehicle support to the military on training exercises and with tests, evaluations, and operational demonstrations of military technology.

Figure 22. CIRPAS Predator A and Pelican aircraft, Marina, CA

CIRPAS originated at the Office of Naval Research as a concept UAV Meteorological Research Facility in June 1993. ONR decided to base CIRPAS out of the NPS because the school offered the unique qualification of being both an academic institution and part of the US Navy. It was thought that UAS technology development required DoD involvement and this could be covered at NPS while still allowing atmospheric science requirements to get properly addressed. During the initial development of CIRPAS, between 1994 and 1996, the organization was based in the meteorology department at the NPS. In Nov 1996 CIRPAS was moved under the Office of the Dean of Research by Dr. Richard Elster, NPS Provost, based on a recommendation by the NPS Board of Advisors. It was thought that CIRPAS could support a boarder set of interdisciplinary research objectives under the Dean of Research than within one specific Department.

The initial idea envisioned use of an Amber UAV, the first forerunner of Predator; however, based on congressional direction not to use this aircraft, an optionally piloted UAV concept was perused, which resulted in Pelican (Cessna 337, O2, Skymaster). Pelican was developed through ONR 6.1 and 6.2 research programs along with Small Business Innovative Research (SBIR) program as a UAV system that could observe diurnal meteorological processes as a UAV and for shorter duration observations as a manned aircraft. Eventually this project became a joint program with NASA resulting in General Atomics (GA) providing the Pelican flight control System based on their GNAT 750 UAV and Predator avionics. A number of Pelican flights were flown remotely with a safety pilot onboard until CIRPAS took delivery of its first UAV system, Altus. Altus was built by GA for NASA and DoE as a high altitude research UAV and was also based on GNAT/Predator technology. At this point, the Pelican project was canceled. In 1998, NAVAIR requested the Pelican be modified and re-purposed as a Predator UAS surrogate. Pelican has served in this role ever since. The Altus UAS was delivered to CIRPAS in 1998 and was flown for the DoE Atmospheric Radiation Measurement (ARM) site at Blackwell, OK. Altus

[18] www.cirpas.org

conducted 24-hour science flights over the ARM site in both 1999 and 2000. The cost of operating Altus, however, was too great for the scientific community to support and the program was cancelled in 2000. After the ARM cancelation, Altus supported a few UAV sensor technology development missions and flew its last mission in 2003. Altus is currently on display at the Naval Aviation Museum annex building. Since 2000, all CIRPAS science missions have been flown on manned aircraft – primarily a Twin Otter – and all CIRPAS UAVs missions have support only applied research projects. In 1999, NAVAIR provided CIRPAS two Predators (and later one more) to support the Tactical Control System (TCS) program. NAVAIR selected CIRPAS to operate Predators because the Altus GCS and ground support equipment (GSE) could also fly the Predator. CIRPAS operated the Predators for numerous users supporting CONOPS[19] development and UAV training projects until 2008. All three CIRPAS predator UAVs are presently located at the Naval Air Warfare Center Weapons Division (NAWCWD), Naval Base Ventura County, Pt. Mugu, CA for use as targets. In 2010, CIRPAS acquired a Sentry UAV system with support from the Army to continue its unmanned aviation mission. CIRPAS currently maintains five Sentry Block 30 UAVs and one GCS. The Sentry UAVs have supported various UAV technology projects.

Figure 23. CIRPAS Pelican parked at Marina Airfield, Marina, CA

Pelican has supported several Marine Corps military training exercises that required a UAV capability but where obtaining an operational Predator UAV was cost prohibitive or where flying a UAV was not practical due to FAA flight restrictions – such as in Marine Expeditionary Unit (MEU) training, Weapons and Tactics Instructor (WTI) courses, and Desert Talon to name a few.

All NPS FX programs (STAN, TNT, JIFX) have leveraged the Pelican's Predator surrogate and command and control (C2) payload capability to support innovative field experimentation. Typically Pelican supported FX by operating out of McMillan Airfield, Paso Robles Municipal Airport, or out of home base, Marina Airfield.

[19] Concept of operations (CONOPS)

2. McMillan Airfield, Camp Roberts CA

In 1997 the then Defense Airborne Reconnaissance Office (DARO) provided CIRPAS $750k to build a dedicated UAV airfield at McMillan airfield[20], Camp Roberts, CA NG base, CA. At the time, McMillan was an unimproved dirt airfield used for C-130 landings (see Fig 24). CIRPAS completed the airfield surface upgrade in 1998. The original program at McMillan was to demonstrate the Reconnaissance Infrared Surveillance Target Acquisition (RISTA) sensor for the Joint Precision Strike Demonstration Office and used the Altus UAV (an early high altitude derivative of the Predator). Several flights were conducted throughout the summer of 1998. Predator flights were conducted between FY98-FY03 for Naval Air Systems Command (NAVAIR) PMA-263's Tactical Control System (TCS) project. This was the driving force for the CIRPAS Predator program, runway and facilities upgrades. CIRPAS also supported the Navy Research Lab's (NRL) Dakota RPV program (FY00-FY01). NRL maintained a permanent crew at McMillan and flew the Dakota UAV regularly. Additionally, the NPS Frog and UCLA's Mule RPV Flight programs utilized McMillan around the same time frame.

In 2002, CIRPAS began supporting two NPS UxS activities called NPS Plume and Smart Warfighting Array of Reconfigurable Modules (SWARM). As previously mentioned, the SWARM project was in support of the pre-STAN NSW research and LT Butner's DA thesis work. In FY03 the Silver Fox UAS began test flights and CIRPAS also supported some NASA flight-testing.

NPS FX use of McMillan Airfield and CIRPAS facilities and assets began with STAN in FY04 and continued through TNT and JIFX. It was also in 2004 that CIRPAS began supporting contractor participation via Technical Support Agreements (TSA) as well as other DoD agencies.

Figure 25 depicts McMillan airfield today. The NPS facilities include a technical operations center (TOC) (the original CIRPAS "double wide"), a Secure Internet Protocol Router Network (SIPRNet) facility, a briefing trailer, CIRPAS management trailer, a Structural Insulated Panels (SIP) hut built in 2013 by the U.S. Military Academy at West Point, and two semi-permanent hangar facilities. The California Army National Guard Shadow UAS facilities (three white hangars top left of figure) belong to the Tactical Unmanned Aerial Systems (TUAS) Detachment 1, Bravo Company, Special Troops Battalion (SBT) of the 79th Infantry Brigade Combat Team (IBCT).

[20] *McMillan Airfield (designated CA62) is located near the post's southern boundary at 35° 43'N 120° 46'W (UTM Grid 10SGQ 025546). McMillan Airfield is 3500' long, 65' wide with 10' shoulders and lays on a heading of 281 degrees and at an elevation of 920'.* See also: http://www.airnav.com/airport/CA62

Figure 24. McMillan Assault Strip 13 May 1994. Note the unimproved surface and lack of support structures.

Figure 25. McMillan airfield 2013. Note the new CANG Shadow UAS unit hangar facility (3 white buildings in NW corner) and the Shadow launch/recovery hard spots near taxi way)

In addition to CIRPAS, the NPS Center for Autonomous Vehicle Research (CAVR) was also an active participant in the STAN and TNT FX research programs.

B. CAVR: CENTER FOR AUTONOMOUS VEHICLE RESEARCH

Like CIRPAS, the NPS center for autonomous vehicle research (CAVR)[21] has been an integral part of NPS FX since the early days of STAN. CAVR, founded in 1987 to educate future DoD leaders in the development and use of unmanned system technologies, has routinely participated in the NPS FX program with several autonomous capabilities. Such technologies have included autonomous underwater vehicles (AUV) (*Aeries)*; unmanned surface vehicles (USV) (*SeaFox);* unmanned aerial vehicles (UAV) (*Scan Eagle, Rascal, Raven, Tern, Zephyr, Unicom)* and various quad/hex-rotor aircraft. CAVR's primary research is focused on advanced control with heterogeneous and collaborative unmanned systems. CAVR researchers and students participated in STAN, TNT, and JIFX programs. Early research focused on autonomous vehicle navigation, control, and communication, multi-vehicle operations and acoustic modem communications, and obstacle avoidance. CAVR operated several unmanned underwater vehicles (UUV) (Aries, Remus) and USV Sea Fox within Lake Nacimiento Reservoir and Monterey Bay in support of FX (see Fig. 27).

Figure 26. One of six NPS CAVR Scan Eagles

Figure 27. CAVR UUVs Aries, Remus and the USV Sea Fox

One of the most significant projects that CAVR researchers participated in took place during TNT 08-2. This event was a collaborative experimental effort between NPS, Navy Special Warfare Command (NSW)–supported by Special Boat Team (SBT) 12, Insitu Inc. (maker of the Scan Eagle UAS-now under Boeing) and Persistent Systems. The primary objective of the San Clemente Island operations was for NSW, SBT-12, and Insitu to demonstrate a proof-of-concept for launch and recovery of a Scan Eagle UAS concept for launch and recovery of a Scan

Figure 28. Kevin Jones integrating a Tern payload

[21] http://www.nps.edu/Academics/Centers/CAVR/AboutUs/AboutUs.html

Eagle UAS from Mark V boats (rapid response to Component need). Scan Eagle was successfully launched from one Mark-V and recovered by another Mark-V on the first attempt (*see Figures 29 and 30*).

Figure 29. Scan Eagle launches from a MK-V during TNT 8-2 off San Clemente Island

Figure 30. Scan Eagle recovering aboard Mark-V off San Clemente Island

Another objective was to establish a Persistent Systems Wave Relay wireless mesh network that linked units ashore at San Clemente Island, Scan Eagle (including the ground control station (GCS)), the Mark-V, USV Sea Fox, and a manned chase boat. The network was then used to

control USV Sea Fox and deliver imagery and targeting data to all nodes.

The third objective this ONR sponsored NPS effort was to detect and track a moving target with the Scan Eagle video camera and relay this information to the Sea Fox USV, which was modified to perform new, higher-speed target inspection maneuvers for MIO. Sea Fox autonomously navigated to the target location and initiated a 'horseshoe" inspection pattern around the target vehicle's port-aft-starboard sector. The onboard camera was linked via the wave relay network and provided the Sea Fox camera to be controlled via the network for visual vessel inspection.

Figure 31 provides a summary the noteworthy CAVR research performed during the TNT research program.

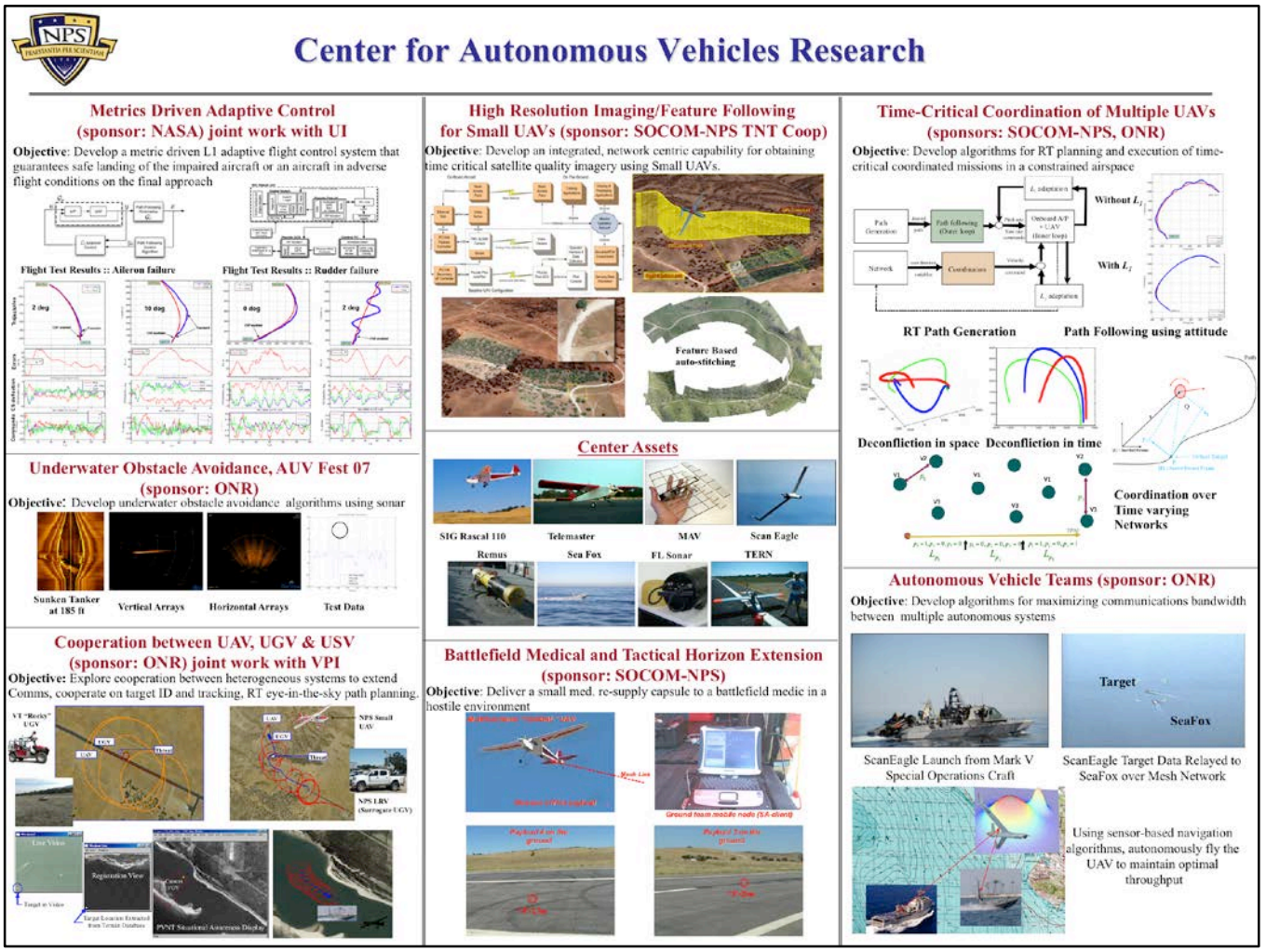

Figure 31. CAVR TNT related research highlights

C. CENETIX: CENTER FOR NETWORK INNOVATION AND EXPERIMENTATION

The U.S. Naval Postgraduate School Center for Network Innovation and Experimentation (CENETIX) was founded in 2004 as a research venue for exploring frontiers of self-organizing tactical networking and collaboration. It provides students and faculty with opportunities for interdisciplinary study of agile adaptive wireless networks, network-controlled unmanned vehicles, sensors, biomedical networking and sensors (Fig. 32), intelligent agents, and situational awareness platforms. CENETIX historically managed the unique student operated NPS-USSOCOM Tactical Network Topology (TNT) and Maritime Interdiction Operations Testbed. The plug-and-play testbed, which includes fixed, rapidly-deployable, and mobile network operations centers, stretches between NPS, Camp Roberts, San Francisco Bay, Ft. Eustis, Port Authority NY-NJ with global reach back to the US experts centers and overseas partner sites in Germany, Sweden, Denmark, Greece and Singapore. CENETIX has supported several national level field experimentation campaigns, including the TNT program as well as the NPS Maritime Interdiction Operations (MIO) experimentation series in collaboration with Lawrence Livermore National Laboratory (LLNL).

Figure 32. CENETIX Biomedical experiments at Camp Roberts

The project work at CENETIX involves cooperation with researchers and students from National Laboratories, top universities and military institutions, including LLNL, MIT, Naval Research Laboratory (NRL), University of California Santa Barbara (UCSB), Johns Hopkins University (JHU), Carnegie Mellon University (CMU), University of Bundeswehr in Munich, Swedish National Defense College, Swedish Naval Warfare Center, Systematik-Denmark, NATO Maritime Interdictions Operations Training Center in Crete, Defense Science and Technology Agency of Singapore, and Salzburg Research. A strong group of industry partners has supported CENETIX team work on TNT and MIO experiments.

Figure 33. CENETIX MIO boarding party experiment

In addition to the NPS FX research, CENETIX also supported the Hurricane Katrina disaster relief efforts in Mississippi by setting up terrestrial as well as wireless ship-to-shore broadband wireless network links in support of US Navy and local first responders. Figure 34 depicts the RedLine 802.16 link from the amphibious landing platform dock ship USS San Antonio (LPD-17).

Figure 34. CENETIX supporting hurricane Katrina relief operations in MS with USS San Antonio (LPD-17)

D. CRUSER: CONSORTIUM FOR ROBOTICS AND UNMANNED SYSTEMS EDUCATION AND RESEARCH

In Feb 2011, the Under Secretary of the Navy (UNSECNAV) provided NPS the authorization to establish the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER)[22]. CRUSER's main objective is "to shape education, research, concept generation and experimentation in maritime applications of robotics, automation, and unmanned systems …and provide a DoD-wide community of interest to exchange research and experimentation results" (UNSECNAV). CRUSER is led by Dr. Ray Buettner (Director) and Dr.Timothy Chung[23] (Deputy Director).

Unmanned systems research has historically been integrated into NPS FX activities since 2002. Together, CRUSER, CAVR, and the NPS Advanced Robotics System Engineering Lab (ARSENL) continue to augment the JIFX program with a rich, multi-talented unmanned systems research group expertise.

Figure 35. Dr. Timothy Chung and CRUSER (From: NPS "In Review Magazine", Oct 2013, p. 20)

[22] http://www.nps.edu/Academics/Centers/CRUSER/index.html
[23] https://wiki.nps.edu/display/~thchung/Home

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APPENDIX A: BRIEF SAMPLING OF TNT FIELD-EVOLVED NETWORK TECHNOLOGIES

Table 5: Sampling of relevant network vendors, associated technologies and COTS products that emerged, were tested, or improved through TNT field experimentation FY02 to present.

Vendor & Associated	Network Technology	TNT Date(s) Introduced	Topology (s)*	Remarks
IEEE Standard, NPS	802.11a/b/g	2002	Pt-Pt | Pt-MPt	Early OSI Layer-1 & 2 networking standards explored in the field often with MANET (OSI Layer-3) routing protocols
BAE	802.16	TNT 08-1,2	Pt-Pt | Pt-MPt and Peer-to-Peer	BAE tested both enhanced 802.16 and mesh variants
GDC4S (General Dynamics C4 Systems)	Tactical Handheld radios	TNT 12-1	Peer-to-Peer	Introduced the Pathfinder mesh radio.
Harris	PRC-152 and 152(A)/117(G) with ANW2 mesh wave form	TNT 08-3,4; TNT 12-1,2,4; TNT 13-1	Pt-Pt | Pt-MPt and Peer-to-Peer	Explored SECNET 11 (secure 802.11); 802.16 (WPPL-D[24]); ANW2 mesh wave form (PRC-152A + 117G) and tactical cellular (KnightLite/KnightHawk)
ITT / Motorola Mesh, Inter4, Sierra Nevada Corp, NPS	802.11 mesh variant	2003-2006	Peer-to-Peer	Explored ITT/Motorola mesh cards in lap tops and Sierra Nevada Corp. Tacticomps for SOCOM.
Redline , NPS	802.16 variant	2002- 2007	Pt-Pt | Pt-MPt	First reliable 802.16 variant produced. AS a result of TNT, USMC adopted Redline as part of WPPL-D POR. Used in NPS-Camp Roberts 100 mi. wireless network backbone.
Silvus Tech.	Mesh + MIMO	TNT 09-2,4 TNT 13-1	Peer-to-Peer	Started as crude prototype now marketing two military versions. Resilience to multipath using MIMO technology.
TrellisWare Tech., Inc. , NPS, MCWL, NSWC Dahlgren	CheetahNet. Mesh + Robust to multipath	TNT 08-4 TNT 09-1,2 TNT 10-1	Peer-to-Peer	Explored ground to ground; air to ground, and air-to-air mesh comms. And below deck (MIO). Resilient to multipath. Extensible to 1000s of nodes.
Persistent Systems (Wave Relay), NPS	High Bandwidth Mesh. 802.11 variant	TNT 08-1,2,3 TNT 09-1 & subsequent	Peer-to-Peer and traditional 802.11 topology	Hi bandwidth, reliable mesh network technology that TNT adopted as the test bed network and SOCOM has matured and supported to develop Suite-B encryption.

[24] http://www.marcorsyscom.usmc.mil/sites/cins/Fact%20Books/NSC/SATCOM/2010%20WPPL-D%20(2)%20Fact%20Sheet.pdf

APPENDIX B: FX RELATED PHOTOS


ALAMEDA COUNTY SHERIFF
FURUNO
HONDA
HONDA


7 11:31AM
NAVY


RPA
NAVY
CIRPAS
McMILLAN AIRFIELD


8 11:21AM
8 11:39AM


783
167783


ariel

APPENDIX C: FX RELATED THESES, PAPERS AND PUBLICATIONS 2002-2013

Papers

2013

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2005

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Student Work

PhD Dissertations

2011

CDR Charles (Chas) Hewgley, USN. Autonomous Parafoils: Toward a Moving Target Capability. Advisor: Dr. Oleg Yakimenko

Masters Thesis

2012

June 2012

Maj Gregory R. Bamford, USMC; VMLO: The Strategic, Operational and Tactical Imperative for a Light Observation Squadron Within the USMC; Advisor Raymond R. Buettner, Second Reader: LCDR William Robinette, Master of Science in Systems Technology; June 2012

September 2012

Ackerson, Brian W.; Low Powered UAS Communications Jammer; Master of Science in Information Warfare Systems Engineering; September 2012

Cummings, Deward L.; Explosive Remnants of War – Collection Points in Stability Operations; Master of Science in Defense Analysis; September 2012

LT Koletsios, Stavros, Helenic Navy; The Integration of Small Satellites in Maritime Interdiction Operations (MIO), Master of Science in Systems Technology; September 2012

Quilon, Donnie A., Rogers, Darren J.; GSM Network Employment on a Man-Portable UAS; Master of Science in Information Warfare Systems Engineering; September 2012

2011

June 2011

Capt Jason Bane, USMC Optimal Employment of Early Warning Sensors. Co-Advisor: Dr. Raymond Buettner & Dr. Karl Pfeiffer

LT Spencer Talley, USN Remotely Triggered Solar Blind Signaling using Deep Ultraviolet (UV) LEDs. Advisor: Dr. Nancy Haegel. Second Reader: Prof. Richard Harkins

September 2011

Capt Dionisio Cooper, USMC UAS Deployment of Taggant Agents. Co-Advisors: Dr. Raymond Buettner & Dr. Kevin Jones

Maj Chad Edwards, USMC USMC Applications for Remotely Piloted Vehicles. Co-Advisor: Dr. Raymond Buettner & Dr. Dan Boger

LT Glenn A. Miller, USN An evaluation of High Resolution Imaging (HRI) payloads for Small Unmanned Aerial Systems (SUAS) for Rapid Precision Target Localization to Provide Information to the Tactical Warfighter. Advisor: Dr. Kevin Jones. Co-Advisor: Dr. Raymond Buettner

Javed Niazi, Pakistan Civ Comparative Analysis of Emergency Response Operations. Co-Advisor: Dr. Raymond Buettner & Dr. Dan Boger

Capt Chad Puff, USMC; Network Management System for Tactical Mobile Ad Hoc Network Segments, Advisor Dr. Alex Bordetsky, Second Reader: John Looney, Master of Science in Information Technology Management, September 2011

Capt Derek Snyder, USMC Organic Counter-Sniper UAS systems. Co-Advisor: Dr. Raymond Buettner & Dr. Kevin Jones

LT Robert Zaborowski, USN Detection and Tracking of Rigid and Articulated Objects from Aerial Imagery. Advisor: Dr. Mathias Kolsch. Co-Advisor: Dr. Christian Darken

2010

September 2010

LT Eric Graewert, USN & LT Troy Smith, USN. ** Advisor: Dr. Raymond Buettner. (Classified)

Capt Mark Gombo, USMC & Capt Samuel VerPlanck, USMC. *Modular Joint Unmanned Combat Aerial Systems Enabling a Single Platform That Performs Multiple Disparate Missions. Advisor: Dr. Raymond Buettner

Capt Dan Rockwell, USMC ** Advisor: Dr. Raymond Buettner. (Classified)

LT Chris Vann, USN Implementation of Software Programmable Radios to Form ad-hoc Meshed Networks to Enhance Maritime Interception Operations. Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Carl Oros

2009

March 2009

Capt David Bieger, USAF, Verification of Buried Improvised Explosive Device (IED) Target Dectection Capability in Target Acquisition Weapons Software (TAWS) Advisor: Dr. Peter Guest. Co-Advisor: Dr. Andreas Goroch, NRL. (Classified)

Maj Joseph E. Delaney, USMC Managing communications with experts in geographically distributed collaborative networks. Advisor: Dr. Alex Bordetsky. Co-Advisor: Mr. Michael Clement

LCDR J. Michel Ferebee, USCG Maximizing Situational Awareness: Improving Situational Awareness with Global Positioning System Data in the Maritime Environment Advisor: Dr. Alex Bordetsky. Co-Advisor: Mr. Eugene Bourakov. Second Reader: Mr. Albert Barreto

LCDR Kent A. Meyer, USN Feasibility Study of Network Operations Center Collaboration to Improve Application Layer Performance. Advisor: Dr. Alex Bordetsky Second Reader: Lt. Col. Karl Pfeiffer

LT Jeffrey S. Olk, USCG Exploring the Lack of Interoperability of Databases within Department of Homeland Security Interagency Environment Concerning Maritime Port Security Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Michael Clement

June LCDR Scott Gardner, USN Visible-to-SWIR Downconversion and its Application to Individual Identification Friend or Foe (IIFF). Advisor: Dr. Nancy Haegel Second Reader: Dr. Peter P. Crooker

Capt Eric Rose, USMC Generation of Mid-Wave Infrared Signature Using Microradiating Devices for Vehicle Mounted Identification Friend or Foe Applications Advisor: Dr. Nancy Haegel. Second Reader: Mr. Richard M. Harkins

September 2009

Maj John F. Dobrydney, USMC IPv6 Tactical Network Management. Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Michael Clement

Maj Marlon McBride, USA & Capt Mustafa Masacioglu, Turkish Army. Control Based Mobile Ad Hoc Networking for survivable, dynamic, mobile Special Operation Force communications. Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Michael Clement

December ENS David Taweel, USN, Midnight Sun. Advisor: Dr. Herschel Loomis. Second Reader: Dr. David Netzer. (Classified)

2008

March 2008

1st LT Ibrahim Demirel, TuAF Aircraft Pilot Situational Awareness Interface For Airborne Operation of Network Controlled Unmanned Systems (US). Advisor: Dr. Alex Bordetsky Co-Advisor: Mr. Eugene Bourakov

Capt Andrew Frey, USAF, Verification of TAWS Target Shell in a Burlap Bag. Advisor: Dr. Peter Guest

LCDR Lauro Luna, USN & LCDR Scott Walker, USN, Frequency Mapping for the Operational Frequency Manager. Advisor: Dr. Alex Bordetsky. Co-Advisor: Mr. Eugene Bourakov

June 2008

ESN Kevin McCadden, USN & ESN Christopher Nigus, USN, Allocation of UAV Search Efforts Using Dynamic Programming and Bayesian Updating. Advisor: Dr. Johannes Royset. Second Reader: Dr. Moshe Kress

September 2008

CPT Sean O'Halloran, USA & LT Derek Rader, USN. Unmanned Aerial or Ground Vehicle Mounted High Sensitivity Radio Frequency Detector For Improvised Explosive Devices Advisor: Dr. Lonnie Wilson. Advisor: Mr. Jim Horning

Capt Adrian Adame, USMC & LCDR Bruce Kong. Performance Management Analysis of IPv6 Sensor On-the-Move Using Commercial Network Management Software Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Michael Clement

Maj Brian Conrad, USMC, LCDR Ioannis Tzanos, Helenic Navy. A Conceptual Framework for Tactical Private Satellite Networks. Advisor: Dr. Alex Bordetsky Second Reader: Mr. Rex Buddenberg

December 2008

Capt Soh Mun Lok Bernarnd, Singapore Army. Hardware in the Loop Implementation of Adaptive Vision Based Guidance Law for Ground Target Tracking Advisor: Dr. Vladimir Dobrokhodov. Second Reader: Mr. Kevin Jones

LT James Elmore, USN. Transient Effects of Polymer-Organic Light Emitting Diodes and Their Impact on Individual Identification Friend/Foe. Advisor: Dr. Nancy Haegel Second Reader: Dr. Peter P. Crooker

Maj Matt Senn, USMC & Maj James Turner, USMC, Analysis of Satellite Communication as a Method to Meet Information Exchange Requirements for the Enhanced Company Concept. Advisor: Dr. Alex Bordetsky. Second Reader: Mr. Joe Welch

2007

March 2007

Chris Chung, Civ, Simulation of Radiowave Propagation in a Dense Urban Environment. Advisor: Dr. David C. Jenn. Second Reader: Dr. Donald Z. Wadsworth

LCDR James Gateau, USN, Extending Simple Network Management Protocol (SNMP) Beyond Network Management: A MIB Architecture for Network Centric Services Advisor: Dr. Alex Bordetsky. Second Reader: Dr. Dan Dolk

Capt Themistoklis Papdopoulos, HAF, Probability Modeling of Multi-Type Autonomous Unmanned Combat Aerial Vehicles Engaging Non-Homogeneous Targets Advisor: Dr. Moshe Kress. Second Reader: Dr. Kyle Lin

June 2007

Capt Robert H. Bledsoe Jr., USMC, ZigBee/802.15.4Applied to a Biologically Inspired Micro Morphing Air-Land Vehicle (MMALV) and MiniWhegs Vehicles for Autonomous Control and Ad-hoc Networking. Advisor: Dr. Xiaoping Yun. Co-Advisor: Dr. Ravi Vaidyanathan. (Restricted)

Capt Clayton A. Craig and Capt Christopher S. Tsirlis, USMC, Command And Control For Distributed Operations: An Analysis Of Possible Technologies, Structure and Employment, Advisor: LtCol Carl Oros, Second Reader: Rex Buddenberg, Master of Science In Systems Technology (Command, Control, and Communications), June 2007

ENS Michael A. Schenk, USN, Real-Time Implementation of an Asynhronousvision-Based Target Tracking System in an Unmanned Aerial Vehicle. Advisor: Dr. Isaac Kaminer Advisor: Dr. Ioannis Kitsios

Capt Patrick Williams, USMC, Development of a Vehicle Based Triggered IFF System. Advisor: Dr. Nancy Haegel

September 2007

Michael Clement, Civ, A Holistic Management Architecture for Large-Scale Adaptive Networks. Advisor: Dr. Alex Bordetsky. Second Reader: Dr. Karl Pfeiffer

Maj Christopher Curran, USMC & Maj Randall Simmons, USMC, Mesh Networks Within A Distributed Operations Framework Utilizing IP Based Radios Advisor: Dr. Alex Bordetsky. Co-Advisor: LtCol Carl Oros

Capt Christopher Griffith, USMC, Unmnanned Aerial Vehicle-Mounted High Sensitivity RF Receiver to Detect Improvised Explosive Devices. Advisor: Dr. Lonnie A. Wilson. Second Reader: Ray A Elliott

Capt Michael McVicker, USMC Effects of Different Camera Motions on the Error in Estimates of Epipolar Geometry between Two Dimensional Images in Order to Provide a Framework for Solutions to Vision Based Simultaneous Localization and Mapping (SLAM). Advisor: Dr. Mathias Kolsch. Advisor: Dr. Kevin Squire

Capt Derek Read, USAF, The Abbott and Costello Effect: or Who's on What, and What's Where When? A Human-Centered Investigation of Communication and Situational Awareness of Military Teams using Net-Centric Warfare Systems. Advisor: Dr. Nita Lewis Miller. Second Reader: Dr. Lawrence Shattuck

Maj Daniel Reber, USMC Optimized Routing of Unmanned Aerial Systems for the Interdiction of Improvised Explosive Devices. Advisor: Dr. Johannes O. Royset Second Reader: Dr. Robert F. Dell. MORS/Tisdale Thesis Award

Maj Brian Rideout, USMC & LT James Strickland, USN, Military Application of Networking by Touch in Collaborative Planning and Tactical Environments Advisor: Dr. Alex Bordetsky. Second Reader: Dr. David Netzer

December 2007

E. Hui, SN Civ, Digital Tracking Array for FM Signals Based on Off-the-shelf Wireless Technologies. Advisor: Dr. David C. Jenn. Second Reader: Mr. Robert D. Broadston

Shay Liang Lee, SN Civ, Tactical Force Protection via UGV-UAV Collaboration. Advisor: Dr. Vladimir Dobrokhodov. Advisor: Richard Harkins

Hui Kok Meng, SN Civ, Digital Tracking Array for FM Signals Based on Off-the-Shelf Wireless Technologies. Advisor: Dr. David Jenn. Second Reader: Robert D. Broadston Capt Gil Nachmani, Minimum-Energy Flight Paths for UAVs Using Mesoscale Wind Forecasts and Approximate Dynamic Programming. Advisor: Dr. Johannes Royset. Second Reader: Dr. Kevin Jones.

LT Johannah Schumacher, USN Time dependent behavior of light emitting polymers for potential Individual Identify Friend or Foe (IIFF) applications. Advisor: Dr. Nancy Haegel

Choon Hon Teng, SN Civ, Design and Performance Evaluation Study of a Prototype of Tactical Unmanned Vehicles. Advisor: Dr. Vladimir Dobrokhodov. Advisor: Dr. Kevin Jones

2006

March 2006

CPT Jasur Khakimbaev, UZB Development of Integrated 3D Terrain Maps for Unmanned Aerial Vehicle (UAV) Flight and Mission Control Support System (FMCSS) Advisor: Dr. Wolfgang Baer. Co-Advisor: Mr. Curt Blais. Second Reader: Dr. Kevin Jones

ENS Tim Kinkaid, USN Study of Micro-sized Technology, Micro-Air Vehicles, and Design of a Payload Carrying Flapping Wing Micro Air Vehicle Advisors: Dr. Isaac Kaminer & Dr. Kevin Jones

LtCol Donald Stewart, USA & LT Eric Turner, USN, Solutions for Universal Wireless Joint Point Technologies in Tactical Mesh Networks. Advisor: Dr. Alex Bordetsky Second Reader: Eugene Bourakov

Maj Christoforos Zachariadis, GR Operation of Longhaul Non-LOS Wireless Tactical Networks. Network Evaluation and Network Management. Advisor: Dr. Alex Bordetsky Second Reader: Maj. Carl Oros

June 2006

LCDR Curtis James Hickle, USN Wind Tunnel Renovation, Flow Verification and Flapping Wing Analysis. Advisor: Dr. Kevin Jones. Co-Advisor: Dr. Garth Hobson

September 2006

LTJG Berat Levent Gezer, TuN Multi-beam Antenna for Radar, Communications and UAV Tracking Based on Off-the-Shelf Wireless Technologies. Advisor: Dr. David C. Jenn Second Reader: Mr. Robert D. Broadston

LT Thomas Haines, USN & CAPT Mike McFerron, USMC, Light Reconnaissance Vehicle. Advisor: Dr. Alex Bordetsky. Second Reader: Dr. Dave Netzer

LtCol Tim Lamb, USA Future Unmanned Aerial Vehicle (UAV) Flight and Mission Control Support System (FMCSS) Design. Advisor: Dr. Wolfgang Baer Co-Advisor: Mr. Edward Fisher

Maj John Glass, USAF & Maj Kent Landreth, USAF. Extending the Tactical Horizon: Networking Aircraft to Enable Persistent Surveillance and Target Development for SOF. Advisor: Dr. Dave Netzer. Second Reader: Dr. Frank Giordano.

Capt Glen Henton, USMC & apt Justin Swick, USMC, Applying Tactical mesh and broad band Clonghaul networking technologies to the USMC Distributed Operations (DO) Platoon. Advisor: LtCol Carl Oros. Co-Advisor: Mr Rex Buddenberg

December 2006

Capt Ohad Berman, IAF, Modeling Cognitive and Tactical Aspects in Hunter-Killer Missions. Advisor: Dr. Moshe Kress. Advisor: Dr. Kyle Lin. Second Reader: Dr. Patricia Jacobs

Chin Chee Kian, SN Civ Experimental Investigation of Pitch Control Enhancement to the Flapping Wing Micro Air Vehicle. Advisor: Dr. Kevin Jones Second Reader: Dr. Chris Brophy

Seng Chuan Lim, SN Civ Computational Investigation of Flapping-Wing Propulsion for a Micro Air Vehicle. Advisor: Dr. Kevin Jones. Second Reader: Dr. Chris Brophy

LT Kyle Matthew, USN, IEDs and CONOPS in Iraq. Advisor: Dr. Lonnie A. Wilson. Second Reader: Dr. David Tucker

Marianna Verett, Civ, Performance and Usage of Biometrics in a Testbed Environment for Tactical Purposes. Advisor: Dr. Alex Bordetsky. Second Reader: Dr. Dave Netzer

2005

March 2005

LT Stephen Burdian, USCG & LCDR Jadon Klopson, USCG Collaborative Applications Used in a Wireless Environment at Sea for Use in Coast Guard Law Enforcement and Homeland Security Missions. Advisor: Dr. Alex Bordetsky. Reader: Glenn Cook

LT Joseph Herzig, USN An Analysis of the Feasibility of Implementing Ultra Wideband and Mesh Network Technology in Support of Military Operations. Advisor: Dr. Alex Bordetsky. Reader: Prof. Glenn Cook

CPT Konstantinos Karapetsas, HAF, Building a Simulation Toolkit for Wireless Mesh Clusters and Evaluating the Suitability of Different Families of Ad Hoc Protocols for the Tactical Network Topology. Co-Advisors: Dr. Alex Bordetsky & Dr. Bert Lundy

LT Greg Milicic, USN An Analysis of Hardware Requirements for Airborne Tactical Mesh Networking Nodes. Advisor: Dr. Alex Bordetsky; Second Reader: Eugene Bourakov

Oliver Tan, Civ, Singapore, A Multi-Agent System for Surface Contact Intent Tracking. Advisor: Dr. John Hiles

LT Peter Hakewessell, USN & LT Jonathan Kaltwasser, USN, SolarwindsORION Data Collection to support TNT Network Monitoring and Analysis. Advisor: Dr. Alex Bordetsky

June 2005

LT Shawn Johnson, USN &Maj Jeff Thiry, USMC, Directed Study, IS4800 Advanced Study in Information Systems – Plan, design and install a Deployable Network Operations Center (DNOC) at McMillan Airfield, Camp Roberts CA, in support of TNT and field experimentation. Professor: Dr. Alex Bordetsky. Customer: Dr. David Netzer

LT Shawn Johnson, USN Deployable Network Operations Center. Professor: Dr. Alex Bordetsky. Customer: Dr. David Netzer

CPT Brian A. Dixon, USMC & CPT William T. Felts, USMC, Design and Implementation of a Networked Architecture Utilizing Capabilities Discovery and Resource Aggregation Advisors: Dr. Gurminder Singh & Mr. John Vitalich

LT Sherrill D. Stamey II, USN Secure Authentication of Images for Global Communications (SAIGC). Advisor: Dr. Gurminder Singh & Mr. Arijit Das

September 2005

ENS James Ackerman, USN Analysis and Design of Vision Based Target Position Estimate Filters. Advisor: Dr. Isaac Kaminer & Dr. Vladimir Dobrokhodov

MAJ Ward T. Blacklock III (Trey), USA RFID Solution for Total Asset Awareness. Advisor: Dr. Alex Bordetsky. Reader: Eugene Bourakov

Capt Francisco Caceres, USMC & Capt Brad Swearingin, USMC. An Analysis of 802.11/16 Technologies as part of the Tactical Internet. Advisor: Dr. Rex Buddenberg; Second Reader: Maj. Carl Oros

Maj Karl Hill, USMC & LCDR Gerard Salazar, USN, Simulation Modeling of Network Attack. Advisor: Dr. Alex Bordetsky; Second Reader: Mr. Steve Iatrou

Maj Jeff "Gimp" Thiry, USMC Directed Study, IS4800 Advanced Study in Information Systems – Planning and Execution of TNT 05-4. Professor: Dr. Alex Bordetsky

LT Chris Marvin, USN 802.16 OFDM Rapidly Deployed Network For Near-real-time Collaboration Of Expert Services In Maritime Security Operations. Advisor: Dr. Alex Bordetsky Advisor: Dr. Dave Netzer

Capt Mike McFerron, USMC & Capt Justin Rumps, USMC, Directed Study, IS4800 Advanced Study in Information Systems – LRV Network Communications Integration. Professor: Dr. Alex Bordetsky. Customer: Dr. David Netzer

LCDR Bill Parrish, USN & LT Dan Tovar, USN, Tactical Wireless Networking In Coalition Environments: Implementing an IEEE 802.20 Wireless End-User Network Utilizing FLASH-OFDM to Provide a Secure Mobile Extension to Existing WAN. Advisor: Dr. Alex Bordetsky. Co-Advisor: James Ehlert Capt Justin Rumps, USMC & Maj Jeff "Gimp" Thiry, USMC, Light Reconnaissance Vehicle. Advisor: Mr. Glenn Cook. Second Reader: Dr. Alex Bordetsky

LT Brad Rose, USN Cooperative vision Based Control of Small UAV's. Advisor: Dr. Isaac Kaminer. Advisor: Dr. Vladimir Dobrokhodov

Capt Koichi Takagi, USMC Applied Warfighter Ergonomics: A Research Method for Evaluating Military Individual Equipment. Advisor: Dr. Nita Lewis Miller. Second Reader: Dr. Nick Dew

ENS Todd. Trago, USN Network Based Control of Small UAV's. Advisors: Dr. Isaac Kaminer & Dr. Vladimir Dobrokhodov

December 2005

LCDR Mitchell Bradley, USN, Transport Imaging for the Study of Quantum Scattering Phenomena in Next Generation Semiconductor Devices. Advisor: Dr. Nancy Haegel

LT Tom Brashear, USN, Development of Inertial Tracking Devices. Advisor: Dr. Isaac Kaminer & Dr. Vladimir Dobrokhodov

2004

March 2004

LCDR Jack Fay, USN, Fleet Network Operations with Decision Support and Augmented Reality Technologies. Advisor: Dr. Alex Bordetsky

LT Jim Nasman, USN, Deployed Virtual Consulting: The Fusion of Wearable Computing, Collaborative Technology, Augmented Reality and Intelligent Agents to Support Fleet Aviation Maintenance. Advisor: Dr. Alex Bordetsky. Advisor: Dr. Gurminder Singh

LT Dave Van Brunt, USN & LT Al Seeman, USN, Operationalizing a Scalable, Reconfigurable Mobile Network Operation Center (NOC) for Wireless Local Area Network (WLAN) Security Research and Development. Advisor: Brian Steckler; Second Readers: Dr. Alex Bordetsky and Dr. Robert Broadston

June 2004

LT Manny Corderovilla, USN Management of Defense Switched Network VoIP Technology in Support of Information and Decision Pre-eminence to Network Centric Warfare. Advisors: Dr. Brian Steckler and Dr. Alex Bordetsky

Captain Gil Garcia, USMC & Captain Dave Joseforsky, USMC, Transformational Communications Architecture for the Common Aviation Command & Control System (CAC2S); Unit Operations Center (UOC); and Command & Control on-the-move Network Digital Over-The-Horizon Relay (CONDOR). Advisor: Dr. Bill Kemple. Second Reader: Brian Steckler

1LT Kristina Jeoun, USAF, Network Operations Center Facilitator. Advisor: Dr. Alex Bordetsky; Second Reader: LCDR Russell Gottfried

CW2 Chris Manuel, USA, MAJ Rick Murphy, USAF & MAJ Ken Paxton, USAF, Surveillance and Target Acquisition Network. Advisor: Dr. David Netzer; Second Readers: Dr. John Arquilla and Dr. Alex Bordetsky

ENS Pamela M. Stefanski, USN Implementation of Ultra-Wideband Technology for Concealed Weapons Detection in Homeland Security and Military Applications. Advisor: Dr. Jovan Lebaric; Second Reader: Dr. Richard Adler

Marinos Dermentzoudis, Establishment of Models and Data Tracking for Small UAV Reliability. Advisor: LCDR Russell Gottfried

ENS Aaron Woolsey Information Exchange Architecture for Integrating Unmanned Vehicles into Marine Missions. Advisor: LCDR Russell Gottfried

September 2004

LCDR Eric Bach, USN &LCDR Marc Fickel, USN, Mesh Networks Operation. Advisor: Dr. Alex Bordetsky

LT Ryan Blazevich, USN Wireless, Long-Haul Multipath Networks. Advisor: Dr. Alex Bordetsky; Second Reader: Dr. Dan Boger

LCDR Sean Cooney, USN Computer Network Operations (CNO) Paradigm Support: Transforming Expectations into Reliable and Manageable CNO Processes. Advisor: Dr. Dan Boger; Second Reader: Jim Ehlert

MAJ Carl L. Oros, USMC, 802.11b WLAN Denial of Service Attacks: In the Lab & In the Littorals. Advisors: Dr. Ray Buettner and Brian Steckler; Second Reader: Mr. Robert Broadston

LCDR Axel Schumann, GE, Navy Airborne Ubiquitous Surveillance and Monitoring Network. Advisors: Dr. Alex Bordetsky and Dr. David Netzer

December 2004

LT Reco Aikens, USN VoIP in ISR Networks. Advisor: Dr. Alex Bordetsky

LT Brian Harp, USN, METOC Sensor Networking via Iridium Satellite System for SOF Unit Situational Awareness. Advisor: Dr. Alex Bordetsky; Second Reader: Dr. Davidson

2003

December 2003

LT Jeffrey Lock, USN & LT John Weber, USN, Cost Analysis for the Development and Operation of a Mobile Wireless Research Facility. Advisors: Brian Steckler, Dr. George Thomas, Dr. Juliette Webb

2002

December 2002

LT Joseph C. Butner, IV Experimental Analysis of Integration of Tactical Unmanned Aerial Vehicles and Naval Special Warfare Operations Forces. Advisor: Dr. Dave Netzer Co-Advisor: Dr. Phil DePoy

APPENDIX D: KEY FX PARTICIPANTS 2003-2014

NPS Facuty/Staff
Ms. Alicemary Adams
Ms. Rosa Akbari
Mr. Tristan Allen
Dr. Wolfgang Baer
Ms. Emily Baker
Dr. Alex Bordetsky
Mr. Eugene Bourakov
Ms. Nancy-Anne Budden
Dr. Raymond R. Buettner
Dr. Tim Chung
Mr. Mike Clement
Mr. Michael Day
Dr. Vladimir Dobrokhodov
Dr. Peter Guest
Dr. Nancy Haegel
Dr. Tony Healey
Dr. Doug Horner
Dr. Kevin Jones
Mrs. Marianna Jones
Dr. Isaac Kaminer
Dr. Mathias Kolsch
Mr. Sean Kragelund
Dr. John McEachen
Mr. Ramsey Meyer
Mr. Aurellio Monarrez
Col Steve Mullins, USA, (Ret.)
Dr. David Netzer
LtCol Carl Oros, USMC, (Ret.)
Mr. Allan Richmond
LTC Gerald "Scotty" Scott, USA, (Ret.)
Mr. Vic Therou
Ms. Nelly Turley
Dr. Lonnie Wilson?
Mr. Scott Wilson
Mr. Ben Wring
Dr. Oleg Yakimenko

CIRPAS/McMillan Staff
Mr. John Bendall
Mr. Bob Bluth
Ms. Carol Collins
Mr. Craig Culp
Mr. Dirk Hale
Mr. Dennis Hamaker
Mr. Ray Jackson
Mr. Walter Krupnak
Mr. Sal Nunez
Ms. Joy Rodriguez
Mr. Harold Wright

CIRPAS Sub-Contractors
Mr. Craig Clark
Mr. Marv Twisselman

AFSOC (Air Boss)
Mr. Jeffrey Golliver
Mr. Sam Nickels
Mr. Patrick Porterfield
Mr. Allan Tew

USSOCOM
Mr. Bob Bean
LtCol Thomas "Bike" Beikirch, USMC
Ms. Brittany Boucher
LtCol Mark Brinkman, USMC
CDR Gordon "Gordo" Cross, USN
CDR David "Chilly" Culpepper, USN
Mr. Michael Guinn
Mr. John Hamiliton
Mr. Michael Harris
Mr. William "Bill" Hellemn
Mr. John Klopfenstein
Mr. Gabriel Lifschitz
Ms. Margaret McCaskey
Mr. Brian Russie
Ms. Lisa Sanders
Mr. Mark Shotland
Mr. Erik Syvrud

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4. COL Guy Lemire, USA
USSOCOM Chair, NPS DA Dept.
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5. Dr. John Arquilla
Chair, NPS DA Dept.
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6. Ms. Nancy Ann Budden
Dir. for Special Operations Technology
NPS DA Dept,
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7. Mr. Dennis Granger
Dep. Dir. J-9 Experimentation, USSOCOM
MacDill AFB, FL

8. Dr. Dan C. Boger
Chair, NPS IS Dept.
Monterey, CA

9. Mr Bob Bluth
Dir. CIRPAS, NPS
Monterey, CA

10. Dr. Garth V. Hobson
Chair, NPS MAE Dept.
Monterey, CA

11. BGEN Keith D. Jones, USA
CDR, 40th Infantry Division
California

12. COL John N. Haramalis, USA
Garrison Commander
Camp Roberts, CA