Manned-Unmanned Teaming of Aircraft – Literature Search

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Table of Contents

List of Figures

List of Tables

1 EXECUTIVE SUMMARY

This report was produced in support of DRDC's Manned-Unmanned Aerial Vehicle Interaction (MUAVI) study which intends to evaluate the utility of unmanned aerial vehicles (UAVs) when used in concert with a manned aircraft in a manner such that both aircraft can influence each other's actions. The objective of this report is to discover and document manned-unmanned teaming (MUM-T) programs, trials and experiments that have taken place in the past ten years. To identify tests, demonstrations and programs, searches were conducted using a mix of scientific and technical databases, military databases, and business and market research databases. In total, around 200 papers were found. Each of these was reviewed and the names and details of any programs mentioned were noted. Once a complete list of relevant programs was compiled, searches were conducted using Google to identify news articles or press releases that could fill in any details the technical papers did not provide. A total of thirteen (13) major programs were identified along with a number of technologies, and one lab devoted to MUM-T.

To maintain an up-to-date understanding of manned-unmanned aircraft teaming, there are several programs and companies that should be monitored. The listing of programs in the body of this paper will show several organizations as clearly standing out in terms of being the most interested, and involved, in MUM-T. These organizations include: the US Army - especially the Aviation Applied Technology Directorate – the Defense Advanced Research Projects Agency, Northrop Grumman, Lockheed Martin, Boeing, and AAI. In addition to these organizations, several ongoing projects should be monitored, including the Manned Unmanned Systems Integration Capability (MUSIC) demonstration program, the TARANIS testing component of the UK's Strategic Unmanned Air Vehicles (Experiment) (SUAV(E)) program, and the German Manned-Unmanned Teaming program. The recently opened Manned Unmanned Operations (MUMO) Capability Development Laboratory should also be closely monitored as they look to be the center of the US Army's manned unmanned teaming research in the near future.

2 BACKGROUND[a]

Unmanned Air Vehicles (UAVs)[b] are used in a variety of military applications such as sensor and weapons delivery platforms. They also have the potential to be used in other applications such as refuelling, communication relays and decoy platforms, to name a few. In all, experts agree that UAVs will have an ever increasing presence in the military battlefield. In some cases, UAVs have the potential to replace manned platforms, while in other cases, UAVs may greatly increase the capabilities of manned platforms as they perform their mission.

DRDC's Manned-Unmanned Aerial Vehicle Interaction (MUAVI) study aims to evaluate the usefulness of UAVs when used in concert with a manned air platform, i.e. when both platforms are flying at the same time and can influence each other's actions. The focus of MUAVI is on the manned Royal Canadian Air Force (RCAF) patrol aircraft, namely the CP-140 Aurora and its future replacement, the Canadian Multi-Mission Aircraft (CMA) as well as fighters, namely the CF-18 and its future replacement, the Next Generation Fighter Capability (NGFC).

The MUAVI study is to be performed in phases. Phase 1, which is already complete, looked at the operational usefulness of UAVs (as defined by key RCAF stakeholders) in a variety of roles when interacting with patrol aircraft and fighters. No technological, cost, legal, or training limitations were taken into account in Phase 1. Phase 2, which is also complete, looked at the technical capabilities and limitations which may impact the usage of UAVs or their payloads in certain roles or while supporting certain missions. In both Phase 1 and 2, the analysis was kept at a high level in order to facilitate, rather than make, the decision regarding the best choice of UAV type, payload and role. This decision will occur in Phase 3 which will analyse the recommendations of phases 1 and 2 along with other factors (e.g.: costing, legal, etc.) and suggest a way ahead for the following phases.

Manned-Unmanned Teaming (MUM-T) of airborne platforms has been experimented with by many nations. For example, the US Army's Manned/Unmanned System Integration Capability (MUSIC) demonstration showed that it is possible for Apache helicopters to direct a fleet of small UAVs.[1] Similarly, trials where the UK's Tornado fast jet controlled UAVs were held in 2007.[2] Finally, commercial MUM-T opportunities are appearing on the market, such as the Kutta technologies Manned/Unmanned Teaming Kit (MUM-TK) which helps facilitate the teaming between manned and unmanned systems.[3]

2.1 Key Issues

In order to display the feasibility of the Canadian MUM-T concept, the MUAVI team needs a better understanding of the currently existing, as well as soon-to-be existing, MUM-T.

[a] Background information provided by DRDC.

[b] Note: the definition of UAVs employed for this project includes traditional and hybrid airships, but excludes munitions and missiles.

The objective of this project is to discover and document the MUM-T opportunities, trials, experimentations, and demonstrations, either commercial or governmental, that have taken place within the last 10 years, or that will take place shortly. Allied nations and large aerospace companies (Boeing, Lockheed Martin, etc.) should be the focus of the investigation. Note that it is understood that trial results and analyses may not be available in the public domain. If such information exists, it should be included. However, in all cases, a summary of the MUM-T interactions, experimental set-up and goals must be included so that the MUAVI team can have an idea of what and where to look for further information through official channels if necessary.

2.2 Key Questions

1. List the MUM-T opportunities, trials, experiments, demonstrations, etc. that occurred within the last 10 years or that will take place shortly. Both the commercial and governmental sectors must be investigated. Only the MUM-T between two airborne platforms (of any type) is of interest.

2. For each items of the list above, give a short description of what took place, where, and give a summary of the key information that could be found, such as the goals, results, types of platforms used, follow-on work to be completed.

3 INTRODUCTION

In order to identify testing and demonstration projects involving manned and unmanned teaming of aircraft, searches were conducted in a variety of scientific, technical and military databases. Searches were restricted to the past ten years only (2003-2013). A complete list of search terms used can be found in 7.1.1. Results were downloaded to EndNote and categorised into their respective programs. Additional searches were conducted using Google to identify non-published MUM-T tests. Once a listing of programs, projects and tests was compiled, additional searches were conducted to locate the information necessary to answer Key Question 2.

In total, 13 MUM-T programs were identified, along with five technologies, and one MUM-T lab. In addition to the programs, five papers detailing academic testing of MUM-T functions were identified, and have been briefly described below.

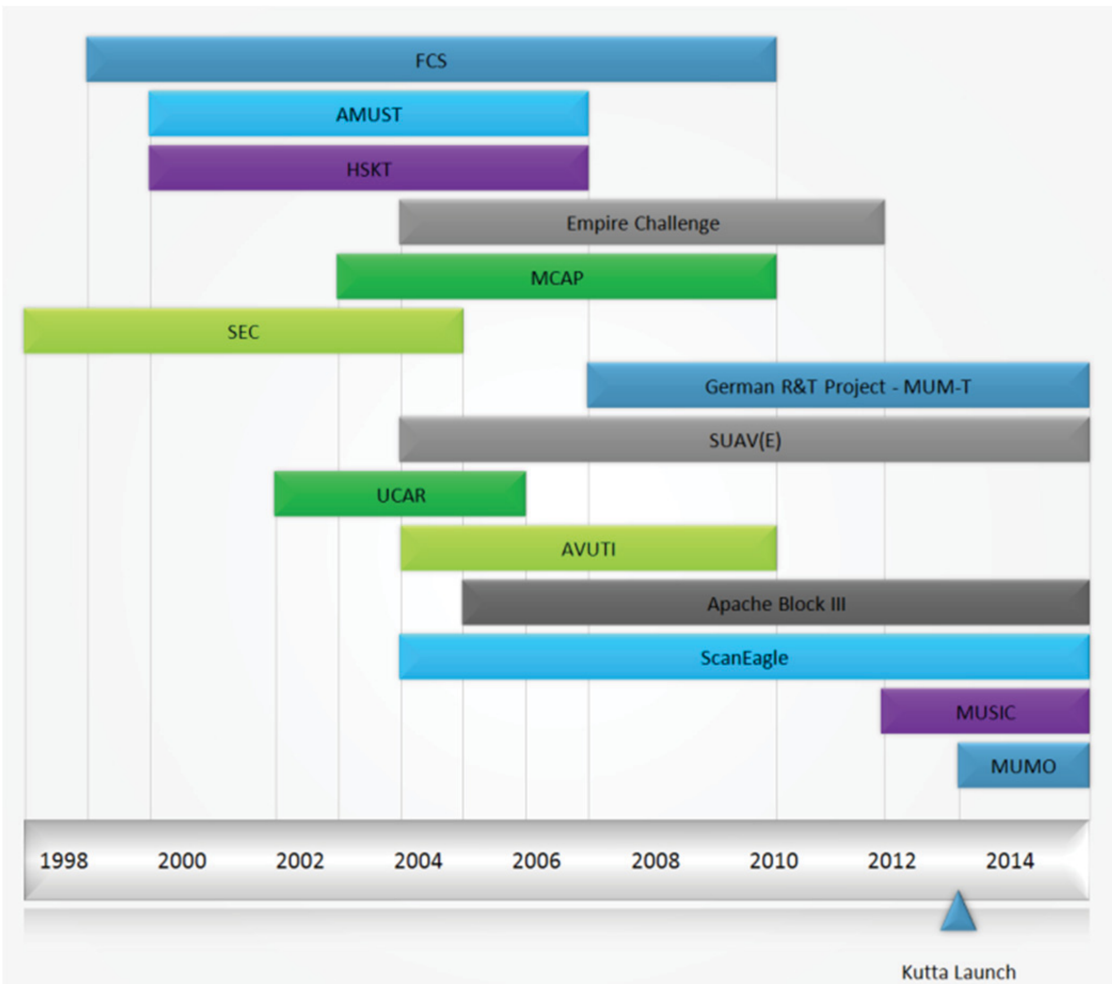
In line with standard practice in the field, the descriptions of each program and test make use of STANAG 4586[4] which outlines the five levels of UAV interoperability. This was intended for use with ground control systems, but it is commonly used in manned-unmanned aircraft teaming. The levels are as follows:

- Level 1 -- Indirect receipt/transmission of UAV-related payload data
- Level 2 -- Direct receipt of Intelligence, Surveillance and Reconnaissance (ISR) data where "direct" covers reception of the UAV payload data by the unmanned control system when it has direct communication with the UAV
- Level 3 -- Control and monitoring of the UAV payload in addition to direct receipt of ISR and other data
- Level 4 -- Control and monitoring of the UAV, less launch and recovery
- Level 5 -- Control and monitoring of the UAV, plus launch and recovery[4]

4 MAJOR PROGRAMS

This section is organized chronologically by program start date, starting with the earliest programs first. Figure 1 below provides the timeline for the programs identified. As no official program dates were identified for Kutta, the triangle represents the launch of their manned-unmanned teaming kit. As shown in Figure 1, many programs were run concurrently.[c]

Figure 1. MUM-T Program Timeline



It was difficult to identify clear timelines for all programs, and it was equally challenging, in all but a few cases, to locate information regarding tests and demonstrations done within the context of a program. In the sections that follow, each program is outlined briefly, and any tests that could reliably be associated with a given program are included in an associated table. Despite extensive searching, there

[c] Only programs with clear timelines have been included in Figure 1.

are many gaps in the tables below, mostly with regards to experimental setup of the various tests and demonstrations. Where the tests involved more than MUM-T an attempt has been made to list only the results related to MUM-T and provide references where further details can be found.

4.1 Software Enabled Control Effort (SEC)

The Defense Advanced Research Projects Agency (DARPA) ran the Software Enabled Control Effort (SEC) program from 1998-through at least 2004, though the program end date is unclear. The intention of this program was to "fully exploit distributed real-time software techniques and services for active modeling, adaptation, robustness and hybrid control of the next generation of complex air vehicles."[5] Only one test that involved manned-unmanned aircraft teaming was identified. Details of the SEC Capstone Demonstration that took place in June of 2004 are included in Table 1. SEC Tests below. Further details of the test, and the experimental setup are provided by Schouwenaars et al.[6]

Table 1. SEC Tests

Test Name/Date	Test Details	
SEC Capstone Demonstration June 2004	Test Location	NASA Dryden, California, USA
	Platforms	• MILP (Mixed Integer Linear Programming)-based guidance algorithm, • T-33 aircraft, • Boeing's UCAV package, • Boeing's Open Control Platform, • CPLEX's Concert Technologies[6]
	Experimental setup	The T-33 acted as a UAV given mission-level commands by an F-15 weapons systems officer (WSO). The communication between the F-15 and "the T-33 was done using a natural language interface, that interpreted human language commands of the WSO and transformed them in real-time into input data for the optimal guidance problem."[6]
	Results	This was the first time an on-board MILP-based guidance system was used to control a UAV in coordination with a manned vehicle. This was also the first time a manned vehicle used a natural language processing interface to control an unmanned vehicle in real time.[6]
	Follow-up planned	Extending the research to platforms with multiple UAVs.
	Level of interoperability	4

4.2 Future Combat Systems (FCS)

The US Army's principal modernization program, Future Combat Systems (FCS), was introduced in 1999 and reformulated in 2003, running through its cancellation in early 2009.[7] FCS was intended to develop both manned and unmanned vehicles that would be linked by a fast battlefield network. One component of this was to use the tactical control data link (TCDL) to team Apaches with fixed or rotary wing UAVs.[8] Also of interest was the design of companion UAVs for the RAH-66 Comanche helicopter that could be operated from the helicopter cockpit.[9] It seems that the tests relevant to MUM-T were conducted as part of both FCS and the Manned/Unmanned Common Architecture Program (MCAP). Please see Section 4.6 on MCAP for the FCS project tests.

4.3 Airborne Manned/Unmanned System Technology (AMUST)

The Army Aviation Applied Technology Directorate (AATD) at Fort Eustis, Va. had two manned unmanned teaming programs running concurrently for much of the early 2000's. The Airborne Manned/Unmanned System Technology (AMUST) program was intended to give an AH-64D Apache control of an RQ-5A Hunter UAV, while the Hunter Standoff Killer Team (HSKT) Advanced Concept Technology Demonstration would network the Apache, Hunter and Army Airborne Command and Control System (A2C2S) BlackHawk into an operational unit. AMUST was an Army Science and Technology Objective[d] developed to integrate Level 4 UAV control into the Longbow Apache, while HSKT was developed to leverage the technology developed for AMUST to provide warfighting capabilities.[10] In 2006, AMUST was folded into HSTK.

The AMUST program was a collaborative effort involving AATD, Lockheed Martin, Northrop Grumman and Boeing. It focused on the connectivity between two manned platforms, the Apache Longbow (AH-64D) and the Command and Control (C2) Blackhawk, and a Hunter UAV. It facilitated communication from the UAV to each platform through the Tactical Common Data Link (TCDL). AMUST-D used decision aiding technology developed under the Rotorcraft Pilots Associate (RPA) Advanced Technology Demonstration (ATD) to assist in controlling the UAV. The combination of decision aiding and UAV control provided the pilot and commander with enhanced situational awareness.[11] The main goal of the program was to "develop and integrate teaming technologies that enable direct video/data receipt, direct payload control and direct flight control of a UAV by manned helicopters with minimal impact to space, weight and workload for the manned system and crew."[11]

Table 2. AMUST Tests

Test Name/Dates	Test details	
Airborne Manned/Unmanned Systems Technology (AMUST) Demonstration,	Organizations involved	• AATD • Lockheed Martin • Northrop Grumman • Boeing[11]

[d] An Army Science and Technology Objective sets a specific technical advancement to be achieved in a given year.

Test Name/Dates		Test details
2001	Platforms	• Apache Longbow (AH-64D) • Command and Control (C2) Blackhawk • Hunter UAV
	Results[e]	• "The Apache received direct video feed (Level 2 control) from the UAV at all times. • The AH-64 controlled both the UAV and the payload cameras (Level 4 control) for 76 minutes. When in control: • Apache directed the aircraft flight patterns by waypoint navigation to the target area • Slewed the camera to identify the targets and send video to ground locations."[12]
	Follow-up planned	Hunter Standoff Killer Team (HSKT) ACTD in 2006
	Level of Interoperability	Level 4

4.4 Hunter Standoff Killer Team (HSKT)

As mentioned in the previous section, the Hunter Standoff Killer Team Program was an Army Aviation Applied Technology Directorate program created to leverage the technology developed in the AMUST program for use in warfighting. The primary goal of the program was to" network U.S. Army helicopters and unmanned aerial vehicles (UAVs) with joint forces strike fighter aircraft to identify and pursue time-sensitive targets that are out of range."[13] HSKT was a six year program that ran from 2000-2006 and was comprised of a four-year Technology Demonstration followed by a two-year Extended User Evaluation.[14]

Table 3. HSKT Tests

Test Name/Dates		Test Details
Hunter Standoff Killer Team (HSKT) Test, 2005	Test location	Patuxent River Naval Air Station, Maryland, USA[13]
	Platforms involved	• UH-60A helicopter (A2C2X) • F/A-18 C/D • F-15E
	Results	During the tests, target data was sent for the first time over Link 16 from an Army UH-60A helicopter (A2C2X) to a Navy F/A-18 C/D and

[e] It was exceedingly difficult to track down any information on the AMUST tests. It is highly likely that these results match this test, but not 100% certain.

Test Name/Dates		Test Details
		a U.S. Air Force F-15E.[13]
	Level of interoperability	4
Hunter Standoff Killer Team (HSKT) ACTD, 2006	Test location	Fort Huachuca, Arizona, USA
	Platforms involved	• AH-64D • RQ-5B Hunter
	Results	"AH-64D executed level of interoperability (LOI) 4 control of a RQ-5B Hunter UAS during a live fire exercise where Apaches lased for their own Hellfire missiles with the Hunter payload."[15]
	Follow-up planned	Multiple tests have been completed. Concrete information on these tests could not be found, however, the Unmanned Systems Integrated Roadmap states that future tests "merely changed the location of the control of the vehicle off the ground.[15]" Upon completion of the ACTD in 2006, the Army transferred the program to its 21st Cavalry, Fort Hood for additional field tests.[16]
	Level of interoperability	4

4.5 Unmanned Combat Air Rotorcraft Program (UCAR)

The Unmanned Combat Air Rotorcraft Program (UCAR) was a four phase program initiated in 2002 that involved DARPA, Northop-Grumman and Lockheed Martin. The original plan was to conduct tradeoffs between mission effectiveness and affordability to develop and optimize an objective system design. After the completion of the concept development studies, DARPA was to choose two contractors for a nine-month preliminary design phase, followed by a system development phase that would yield two prototype vehicles.[17] The system, which would enable ground maneuver force superiority, had to be able to collaborate with multiple UCARs and other manned and unmanned systems. Unlike other UAVs, the UCAR was not to have a dedicated ground station. Instead, the system was to integrate into existing command and control platforms, such as the Future Combat Systems command and control vehicle and combat aviation. Capable of autonomous mission planning while in flight, the UCAR was to request guidance from a human operator only for tasking and final weapons authorization.[17] The final phase was to be completed in 2009 and would have involved the Army taking ownership of the winning platform and beginning system design and development with the resulting system being fielded in 2012. However, "UCAR was cancelled in 2005 when the US Army lost interest" and pulled its money from the project.[18] Before UCAR's cancellation, DARPA had identified four areas it believed were critical to the program's success:

- autonomy and collaboration of the air vehicles

- low-level autonomous flight
- affordability and survivability
- target recognition.

In these areas, the project had completed component testing to reach NASA's Technology Readiness Level (TRL) 4 standard.[17]

4.6 Manned/unmanned Common Architecture Program (MCAP)

The Manned-unmanned Common Architecture Program (MCAP) is another US Army Aviation Applied Technology Directorate program. The program started in 2003, and ran through 2008. It involved Rockwell Collins,[19] Boeing, and EFW.[20] The goal of MCAP was to develop an affordable, high-performance embedded mission processing architecture for potential application to multiple aviation platforms.[21] In order to meet this goal, MCAP analysed Army UAV and helicopter missions, identified supporting subsystems, surveyed advance software and hardware technologies, and defined computational infrastructure requirements. The project then selected a set of commercial off the shelf electronics and software as well as modular open system standards and developed network architectures, mission processors, and software infrastructures to support the integration of new capabilities, life cycle cost reductions, and interoperability. The project integrated the new mission processing architecture into an AH-64D Apache Longbow and participated in a number of tests.[21]

MCAP participated in the "Future Combat Systems (FCS) network-centric operations field experiments in 2006 and 2007 at White Sands Missile Range (WSMR), New Mexico and at the Nevada Test and Training Range (NTTR) in 2008. The MCAP Apache also participated in PM C4ISR On-the-Move (OTM) Capstone Experiments 2007 (E07) and 2008 (E08) at Ft. Dix, NJ and conducted Mesa, Arizona local area flight tests in December 2005, February 2006, and June 2008." MCAP successfully transitioned to the Apache Attack Helicopter Block III System Development and Demonstration (SDD) effort and is the basis of the new mission avionics architecture.[21]

Table 4. MCAP Tests

Test Name/Dates	Test Details	
MCAP – FUTURE COMBAT SYSTEMS FIELD EXPERIMENT 1.1, October 2006-February 2007	Test location	White Sands Missile Range, New Mexico, USA
	Platforms involved	MCAP Apache equipped with an AN/VRC-99A IP network radio, SOSCOE Micro Edition 1.5 middleware, and an OFP gateway application
	Experimental setup	"The AN/VRC-99A, acting as a surrogate for the objective WNW (Wideband Network Waveform) radio, connected the Apache to a Command and Control vehicle which was also connected to other participating nodes through SLICE IP radios acting as surrogates for the objective SRW radios. This AN/VRC-99A/SLICE network allowed the SOSCOE middleware and gateway application on the Apache to interoperate with the Command and Control (C2) Station, platoon

Test Name/Dates		Test Details
		vehicles, Unattended Ground Sensors (UGS), dismounted soldiers, and the Class I UAV (unmanned air vehicle)." [21]
	Results	"The Apache contributed to and shared Blue and Red Force situational awareness (SA) information, conducted call for fire missions and received still images and streaming video." [21]
MCAP – PM C4ISR On-the-Move (OTM) Capstone Experiments, July and August 2007	Test location	Ft Dix, New Jersey, USA
	Platforms involved	Apache
	Experimental setup	The SLICE IP "radio was used to network the Apache with dismounted Future Force Warriors and interoperate using the CoT message set."
	Results	"Apache was able to send position information, receive Red and Blue SA data, and receive and confirm Call for Fire (CFF). Unfortunately, aircraft related problems prevented the helicopter from flying during the exercise and all demonstrations were conducted with the Apache on the ground."[21]
FCS FIELD EXPERIMENT 2.1/JOINT EXPEDITIONARY FORCE EXPERIMENT, February – April 2008	Test location	Nevada Test and Training Range, USA
	Platforms involved	Apache and Surrogate UAV
	Results	• "FCS Class I UAV Surrogate (CLI(S)) video dissemination over SFF-A (Small Form Factor – A) and WSRT (Wearable Soldier Radio Terminal) radios into the Brigade SLICE network and display in the MCAP Apache; • CLI(S) Red and Blue SA data transmitted to the FCS COP (common operating picture); Red, Yellow, and Blue SA from FCS COP disseminated to the MCAP Apache; • MCAP Apache MTADS sensor video down-linked to the One System Common Ground Station (OSGCS) via Tactical Common Data Link (TCDL); OSGCS processed the video and disseminated it to the TOC (Tactical Operations Center) where it was passed to the high side of the network and into the GIG (Global Information Grid) and viewed at Langley AFB, Virginia;Surrogate Class IV UAV (CLIV(S)) and MCAP Apache MUM (Manned/Unmanned) Level 2 teaming via TCDL; • CLIV(S) cross banding of MCAP Apache sensor video into HNW (High-bandwidth Networking Waveform) network and down-linked to the OSGCS; OSGCS processed the video and sent it to the TOC where it was passed to the high side of the network and into the GIG (viewed at Langley AFB); the HNW network simultaneously sent both the CLIV(S) and the MCAP Apache video to the OSGCS

Test Name/Dates		Test Details
		via different sockets on the same IP connection; • An MCAP Apache ground-based emulator was used to control a Tactical Targeting Network Technology (TTNT) radio to receive and display B-52 video."[21]
VIDEO STREAMING FLIGHT TESTS, June 2008	Test location	Mesa, Arizona, USA
	Platforms involved	Apache
	Experimental setup	"MCAP flight tested the TCDL video streaming, tactical whiteboard (TWB), and precision coordinate extraction (PCE) functions and TTNT."[21]
	Results	"Using TWB, a TCDL user captures still images from the MCAP Apache video stream, annotates the images with descriptive graphics and text, and transmits them back to the aircraft to be viewed on the cockpit displays. PCE georeferences captured images and extracts 3-dimensional coordinates of a selected point. TCDL then sends the coordinates back to the MCAP Apache. Once the coordinates are received on the aircraft, the MCAP Apache slews the MTADS to the coordinates extracted from the TWB and transmitted via the data link. TTNT was also demonstrated during these flight tests. These capabilities have the potential to improve coordination between the sensor and shooter and reduce engagement timelines."[21]
PROGRAM MANAGER C4ISR OTM CAPSTONE EXPERIMENT, July and August 2008	Test location	Ft. Dix, New Jersey, USA
	Platforms involved	Apache
	Results	The "Apache demonstrated the Mini-TCDL video streaming, tactical whiteboard, and precision coordinate extraction functions and the SLICE SRW CoT functions in flight."[21]

4.7 Armed VTOL UAV Testbed Integration (AVUTI)

The Armed Vertical Take Off and Landing (VTOL) Testbed Integration (AVUTI) program was a joint effort of the Army's Aviation Applied Technology Directorate, SAIC, and ATI[22] that ran approximately between 2004 and 2009.[f] The program intended to use the Vigilante system platform "as a vehicle for demonstrating UAV technologies, to investigate the platform and manned-unmanned teaming issues associated with weapons engagements from Class III UAVs."[22] The table below highlights the only test identified for the AVUTI program.

Table 5. AVUTI Tests

Test Dates	Test Details	
Tests Completed December 13 and 14, 2004	Test location	U.S. Army's Yuma Proving Ground, Arizona, USA[22]
	Platforms involved	Vigilante UH-1N Huey helicopter[22]
	Results	Successful live-fire of four 2.75" unguided rockets from the Vigilante VTOL UAV system during flight testing. The "rocket firing demonstration represents an aviation first as they were executed while the Vigilante system and its payload was under air-to-air control from a control console installed aboard a UH-1N Huey helicopter flying a loose formation on the Vigilante system."[22]
	Level of interoperability	Not mentioned. It's clear they achieved level 4 interoperability, but given the use of a vertical takeoff and landing aircraft it's possible they achieved level 5.

4.8 Empire Challenge

Empire Challenge was a demonstration/testing program that took place one month out of each year, and was intended to demonstrate and test Intelligence, Surveillance and Reconnaissance (ISR) technologies with the goal of improving coalition interoperability within the imagery intelligence architecture.[23] The program involved Coalition forces (United States, United Kingdom, Canada, and Australia) and other unnamed nations[23], and ran from 2004 through 2011 when it was replaced by two other programs: Enterprise Resolve, which involves forming partnerships with military and intelligence experts running their own demonstration and testing programs, and Enterprise Challenge, a small-scale interoperability demonstration program.[24] In regards to MUM-T, it is Empire Challenge 2009 (EC09) that is of interest, and the relevant results on EC09 are outlined below.

[f] Please note that these dates are not exact, they are approximations based on the information available.

Table 6. Empire Challenge Tests

Test Name/Date		Test Details
Empire Challenge 2009	Test description	Empire Challenge 09 was a three week long final demonstration testing around 40 initiatives for gathering and sharing intelligence, surveillance and reconnaissance data before they enter service. "Run by U.S. Joint Forces Command (USJFCOM), the "live fly" EC09 includes simulations of ambushes, sniper and "shoot and scoot" mortar attacks, making and planting improvised explosive devices (IED), kidnapping and other elements of irregular warfare."[25]
	Program goals	Successfully demonstrate how manned command and control aircraft can direct and manage unmanned aircraft to enhance image collection and target identification.
	Test location	"Based at the USJFCOM Joint Intelligence Laboratory (JIL) in Suffolk, Va., the virtual platforms were linked to the "live-fly" exercise at the Naval Air Weapons Station (NAWS) in China Lake, Calif., as well as the Combined Air Operations Center-Experimental at Langley Air Force Base, Va."[25]
	Platforms involved	• E-8C Joint Surveillance Target Attack Radar System (Joint STARS) • E-2 Hawkeye Airborne Early Warning and Control (AEW and C) aircraft • E-2 Hawkeye developmental test bed, RQ-4 Global Hawk unmanned aircraft reconnaissance system • MQ-8B Fire Scout vertical takeoff and landing unmanned system • MQ-5B Hunter medium altitude unmanned aerial system.[25]
	Experimental setup	Virtual physics-based and operational flight program simulations of multiple Northrop Grumman platforms, including Joint STARS and E-2 Hawkeye were run in a collaborative manner in order to demonstrate "interoperability between multiple manned and unmanned aircraft via an airborne Web services architecture."[25]
	Results	"The virtual Joint STARS integrated the Battle Management Command and Control (BMC2) architecture providing constellation management along with UAV control and multi-level security capability sets which enabled the platform to demonstrate an expansion of its current ISR role to include automated UAV image collection and development of target quality solutions to support strike engagements […].The net effect of this ISR sensor tasking and command and control network was a reduction in both the 'kill-chain,' the time it takes to find, identify, and engage a target, and the operator workload required to accomplish the task."[25]
	Follow-up planned	Unknown

4.9 Strategic Unmanned Air Vehicles (Experiment) (SUAV(E))

The Strategic Unmanned Air Vehicles (Experiment) (SUAV(E)) is a joint program between the UK and the US; it started in 2004 and is ongoing. "The Directorate of Equipment Capability Deep Target Attack, DEC(DTA), has a requirement for a Deep and Persistent Offensive Capability (DPOC) to enable the timely engagement of static and mobile, targets deep behind enemy lines."[26] The SUAV(E) Integrated Project Team (IPT) is responsible for directing the work required to establish the potential of UAVs to meet the DPOC requirement.[26] The primary goal of SUAV(E) is to assemble evidence to inform a decision on UK forces future use of UAVs and procurement options.[26] The SUAV(E) program took a two-pronged approach to "explore technology maturity and risks, and gather evidence on cost, interoperability and operational concepts." [26] This two-pronged approach takes the form of two projects. Project Churchill was a collaborative program, which began in 2004 and ended in 2010, that explored "unmanned combat air systems, Concepts of Operation, coalition interoperability, Whole Life Costs and technological feasibility (but not technology development or transfer) employing a number of technologies including distributed simulation between UK and US." [26] Project Taranis was SUAV(E)'s Technology Demonstrator Program which ran from 2006-2010. The project was directed towards designing and flying an unmanned aircraft, gathering the evidence needed to inform decisions about a future long-range offensive aircraft and evaluating UAVs' contribution to the RAF's future mix of aircraft.[26]

A series of successful flight trials were conducted in March 2007 using QinetiQ's Tornado Integrated Avionics Research Aircraft (TIARA) as the command-and-control aircraft with manned BAC 1-11 aircraft acting as a surrogate UAV. [2]

The TARANIS technology demonstrator vehicle was scheduled to undergo flight testing in the test ranges at Woomera in South Australia in 2011 but these were delayed until 2013. As of October 2013, flight trials are underway.[27] This "first flight follows a three-year delay and more than 55 million pounds (US $83.1 million) in additional costs caused by technical issues, an increase in the list of requirements and extended risk mitigation work on Taranis."[2] No results from the trials have been released yet.

4.10 Apache Block III

The Apache is an Army attack helicopter, and has been used in combat since 1989. It has gone through two major overhauls, the second one being the design of the Block III. Boeing was awarded the contract for development of the Block III in 2005, and the first flight test was conducted in 2009. The first Block III was delivered to the US Army in late 2011. The Block III includes, among many other improvements, the capability to control a UAV.[28] The AB3 Limited User test, conducted in November 2008 included testing the MUM-T capabilities of the AB3 aircraft with a substitute UAV operating under normal airspace restrictions. This test led directly to developing the AB3NAT in order to provide training prior to the Initial Operational Test and Evaluation (IO&T). The first flight of the mast-mounted unmanned aerial systems tactical common datalink assembly (UTA) occurred in January 2009.[29] The AB3NAT test outlined below was developed as a risk reduction effort for the IO&T that would proceed afterwards.[30] It should be noted that four years of developmental testing was completed prior to the IO&T.[31]

Table 7. Apache Block III Tests

Test Name/Dates		Test Details
First Flight of UTA, January 23, 2009	Testing description	Testing of the mast-mounted unmanned aerial systems tactical common datalink assembly (UTA).
	Platforms involved	• AH-64D • Boeing H-6 Little Bird
	Results	"Successful connection of AH-64D and unmanned Boeing H-6 Little Bird helicopter which demonstrated ability to acquire UAV in flight and display sensor video in Apache cockpit."[29]
	Level of Interoperability	2-4
AB3 National Airspace Trainer (AB3NAT), February 2, 2012	Testing description	A risk reduction effort for the IO&T described below. The AB3NAT test also provides training opportunities for tactical units without having to operate in normal restricted airspace.[30]
	Test location	University of Alabama – Huntsville, USA
	Platforms involved	AH-64D Longbow Apache Block III
	Results	The demonstration showed that a manned platform is capable of acting as a surrogate UAV in order to emulate the capabilities of MUM-T.[30]
	Level of Interoperability	2-4
Initial Operational Test and Evaluation - March 16, 2012, through April 13, 2012	Testing description	The IO&T is a "series of combat-like assessments and evaluations placing the aircraft in operationally relevant scenarios as a way to prepare the platform for full-rate production."[31] It included "force-on-force missions with a dedicated opposing force; live fire of all weapon systems; and threat penetration testing of AB3 computer networks. "[32]
	Test location	National Training Center in Fort Irwin, California, USA
	Platforms involved	AH-64D Longbow Apache Block III
	Results[g]	"AB3 crews were consistently able to establish a datalink with Gray Eagle to receive UAS video. Crews had some difficulty establishing and maintaining control of the Gray Eagle sensor." [32]

[g] Please note, only results relating to MUM-T have been included.

Test Name/Dates	Test Details
Follow up[h]	"Continue to refine tactics, techniques, and procedures for teaming with UASs. Determine the root cause for datalink dropouts and improve the stability of the tactical command datalink for control of UAS sensors."[32]

4.11 German R&T project MUM-T

The German R&T project was created to investigate MUM-T and the capacity to use German Army helicopters to participate in MUM-T. The program began in 2007 and is ongoing, and is a collaborative project involving the German Federal Office of Defense Technology and Procurement, ESG Elektroniksystemund Logistik- GmbH (ESG), Universität der Bundweswehr München and Deutsche Zentrum für Luft- und Raumfahrt. [33] It was started to answer two major questions:

- Will German Army Aviation gain an operational advantage of joint operations of manned and unmanned helicopters? In particular when taking German cargo and attack helicopters CH-53, NH90 and EC 665 (TIGER) into account.
- What can a possible technical solution look like?[33]

A central goal of the program is to develop technology that would enable three tactical UAVs to be controlled by a two person aircrew at level of interoperability four and five.[34]

Tests and demonstrations were conducted on an annual basis using cockpit simulators and German helicopters. "Additional technical evaluations were performed during real world flight tests involving a test helicopter (UH-1D) and relevant UAV components integrated in a ground based system." [33] Methods used during these evaluations include – the NASA Task Load Index, Situation Awareness Global Assessment, Adopted Cooper Harper/Bedford Rating Scales as well as interviews and questionnaires. [33] The tests showed the potential of teaming manned and unmanned aerial vehicles, but they also showed the difficulty in tuning the workload. Due to the need for increased levels of UAV autonomy, and issues with certification and qualification the TIGER will likely remain limited to LOI 3 for the time being. Despite those problems, and some issues with the sensors, LOI 4 was attained in some flight tests. [33] The details from tests completed in 2010 and 2011 are included below.

[h] Please note, only results relating to MUM-T have been included.

Table 8. German R&T MUM-T Tests

Test Name/ Dates	Test Details	
2010 Testing[34]	Testing description	A rotary-wing UAV flew with the cognitive automation system on board and conducted a representative mission.
	Test location	ESG Technology Center, Germany
	Platforms involved	German cargo and attack helicopters • CH-53 • NH90 • EC 665 (TIGER)
	Experimental setup	Rotary wing UAV flew with a cognitive automation system on board to conduct a representative mission. A fixed wing UAV demonstration was also conducted which demonstrated route and area reconnaissance.
	Results	High bandwidth imagery was transmitted and woven together to create real-time maps.
2011 Testing[34]	Testing description	German Army pilots evaluated the system in an extensive flight simulator campaign that involved demanding missions and dynamically changing scenarios. The team tested selected functions on board mini-UAVs, with a surrogate ground-control station (GCS) acting in place of the helicopter.
	Test location	ESG Technology Center, Germany
	Platforms involved	German cargo and attack helicopters • CH-53 • NH90 • EC 665 (TIGER)
	Experimental setup	Simulated missions. Human in-the-loop experiments on crew behaviour, workload, situation awareness, gaze tracking, etc.
	Results	Despite anticipating an increased workload when adding the task of controlling a UAV, pilots actually found a reduction of workload.
	Follow up	• Continued development of ESGs' UMAT demonstration platform; • "Preparation of MUM-T flight tests focusing on operational aspects, e.g. UAV command and control while screening payload data[…]; • Addressing certification aspects to figure out certification requirements regarding the overall system design." [33]

4.12 Video from UAS for Interoperability Teaming Level 2 (VUIT-2)

Video from UAS for Interoperability Teaming Level 2 (VUIT-2) is more a technology than a program, but it is included here because it is a technology explicitly designed to allow level of interoperability 2 between aircraft. VUIT-2 enables Apache aircrews to view streaming video and metadata from a variety of UAVs, and allows the crew to downlink either the UAV video or the AH-64D's own sensor video to ground forces. VUIT had three primary goals:

- To deploy technological advances applied to US Army aircraft in a safe and timely manner.
- To design, develop, fabricate, integrate, and test an Apache VUIT-2 system
- Validation and verification of AH-64D Block I and Block II aircraft for fielding a demonstration Battalion.

VUIT-2 was developed by the US Army, Lockheed Martin, AAI Corporation, Camber, and L-3 Communications. The technology was deployed late 2008 in Boeing AH-64 Apache attack helicopter.[35] As of 2009, the army was beginning work to integrate VUIT-2 systems onto its medical evacuation (MEDEVAC) helicopters, Sikorsky UH-60 Black Hawk command-and-control helicopters and the emerging Aerial Common Sensor intelligence aircraft. [36]

Table 9. VUIT-2

Test Name/ Dates		Test Details
Bench Tests 1 and 2 - 2007	Test description	To enable the AH-64D aircraft to receive multiband video and metadata signals transmitted from a UAV aircraft and view them in the cockpit. "This concept was expanded to include enabling the AH-64D to not only send the received video and metadata from the UAS to a one source remote video terminal (OSRVT) ground station or a ground control station (GCS) but also send target acquisition designation sight (TADS) or modernized target acquisition designation sight (MTADS) video to the same ground receiving station or different ground receiving stations." [37]
	Test location	Lockheed Martin (LM) in Orlando, Florida; AATD at Fort Eustis, Virginia, USA
	Experimental setup	Bench testing on a prototype system with all VUIT-2 system components.
	Results	"The first AATD bench test allowed AATD to conduct not only hardware-in-the-loop testing (by building a bench test system around an AH-64D aircraft) but also a full system test before a prototype system was installed. The second bench test system was established at LM's location to enable the full system testing of production parts before they were shipped to AATD for kitting and government quality assurance. This action enabled LM to keep the prototype bench test system independent and free from production-line requirements. The action also allowed the VUIT-2 team to make design improvements, test these changes, and assist in troubleshooting during functionality tests and acceptance test procedures (ATP)."[37]

Test Name/ Dates	Test Details	
	Level of Interoperability	2
Phase 1 Testing – Dates unknown	Testing description	Ground-level power checks on harnesses and LRUs. Full system and limited functional checks on the system. Failure Modes, Effects, and Criticality Analysis (FMECA).[37]
	Test location	Army Airfield at Fort Eustis, Virginia, USA
	Platforms involved	Shadow UAV simulator and Ground OSRVT
Phase 2 Testing – Dates unknown	Testing description	Qualitative electromagnetic compatibility (EMC) testing on the ground and in flight, limited handling qualities evaluations, limited functionality testing, ground tests and flight tests, functionality testing of the VUIT-2 system to receive Raven and Warrior A simulation and emulation.[37]
	Test location	Fort Eustis, Virginia, USA
	Platforms involved	• Shadow UAV • OSRVT station
Phase 3 Testing – Dates Unknown	Testing description	"Full functionality testing with Shadow UAV in flight transmitting video and metadata and with ground OSRVT stations displaying and recording TADS and OSRVT video transmitted from AH-64D VUIT-2 aircraft. The CTT conducted live fire testing for gathering vibration data and its effects on the OSRVT and MTCDL systems operating during engagements with 30-millimeter (mm) cannon and 2.75 in rockets."[37]
	Test location	Fort Rucker, Alabama, USA
	Platforms involved	• Shadow UAV • OSRVT station • AH-64D

4.13 Manned Unmanned Teaming interoperability level 2 (MUMT2)

Manned Unmanned Teaming interoperability level 2 (MUMT2) is the Army's follow-on system to VUIT2 and was intended to be the "next evolution" of level two teaming capability for the Apache helicopters. The program was initiated by the Army in April 2010 with Science and Engineering Services, an integrator for Boeing, L-3 Communications and AAI. MUMT2 has a longer range than VUIT2, and it has been integrated directly into the cockpit.[38] This system was tested as part of both the MUSIC exercise,[1] and the Apache Block III IO&T.[39]

4.14 Level 2 Manned-Unmanned Teaming System (L2MUM)

Like VUIT-2, the Level 2 Manned-Unmanned Teaming System (L2MUM) is a technology rather than a demonstration project. L2MUM was developed by L3 Communications and AAI Corporation, and stems directly from the success of VUIT-2. L2MUM offers more capabilities than VUIT, including the ability to send full motion video on four different frequency bands: C, L, F and Ku. The system also has superior range and weighs less than the VUIT-2.[35] L2MUM was deployed in 180 Kiowa Warriors in 2011[40], and allows their crew to view sensor data from unmanned aircraft systems (UAS) and send data from the helicopter's sensors to the ground.[35] No tests on L2MUM were identified.

4.15 Tactical Video Data Link (TVDL)

Emulating VUIT-2 is the Tactical Video Data Link (TVDL) system designed by Elbit Systems. Following a successful demonstration of TVDL at Patuxent River Naval Air Station, Maryland, in June 2008, the US Naval Air Command contracted Elbit Systems to supply TVDL systems for the US Marine Corps AH-1W attack helicopters. The TVDL will give AH-1 crews access to video and targeting data feeds from UAVs, as well as the ability to retransmit this data to other aircraft or ground stations.[41]

4.16 ScanEagle

The ScanEagle is a UAV designed for persistent, low altitude intelligence, search and reconnaissance; it is a joint effort between Boeing and its subsidiary Insitu. Development dates are unclear, but the ScanEagle entered the market in 2004 and continues to be deployed. [42]

Numerous flight tests have been conducted over the course of the ScanEagle's development, but only one test explicitly involving MUM-T was identified, outlined below.

Table 10. ScanEagle Tests

Test Names/Dates	Test Details	
March 16, 2009	Test location	Boeing's Boardman Test Facility in eastern Oregon, USA
	Platforms involved[43]	• Royal Australian Air Force (RAAF) Wedgetail 737 Airborne Early Warning and Control (AEW&C) • Three ScanEagle UAVs
	Experimental setup	"Operators in the AEW&C aircraft used Boeing's UAS battle management software to issue NATO-standard sensor and air vehicle commands via a UHS satellite communication link and a ground station relay....The three ScanEagles were launched from Boeing's Boardman Test Facility in eastern Oregon, approximately 120 miles (190 km) away from the airborne Wedgetail. Operators tasked them with area search, reconnaissance, point surveillance and targeting."[43]
	Results	"The ScanEagles demonstrated extended sensing, persistent intelligence,

Test Names/Dates		Test Details
		surveillance and reconnaissance (ISR) and manned-unmanned teaming. The unmanned aircraft also sent back real-time video imagery of ground targets."[43]
	Follow-up	A follow-up demonstration was scheduled to be conducted in May 2009 at RAAF Base Williamtown in New South Wales, but no documentation regarding the test was found.[43]

4.17 Manned-Unmanned System Integration Capability (MUSIC)

Manned-Unmanned System Integration Capability (MUSIC) is a US Army demonstration program explicitly looking at manned-unmanned aircraft interoperability. The overall goal of the program was to test teaming between manned and unmanned aircraft to promote the transfer of data and imagery between platforms. To achieve this goal, MUSIC had multiple objectives including "demonstrating advancements made in manned-to-unmanned teaming, or MUM-T; demonstrating interoperability among unmanned systems through the Universal Ground Control Station, known as UGCS, Mini-UGCS, or M-UGCS, and the One System Remote Video Terminal, or OSRVT; and highlighting PEO Aviation's open architectural approach that allows multiple control nodes and information access points via the Tactical Common Data Link, or TCDL."[1] The first test took place in 2011, and is detailed below. Follow-up testing is planned for every two years. MUSIC II is planned for April 2014, and is expected to focus on mission expansion and using UAS more efficiently.[44]

Table 11. MUSIC Tests

Test Name/ Date		Test Details
Test - September 14-16, 2011	Description	According to Jane's, this was the first time "manned and unmanned aircraft were organised in the same unit under a single aviation commander".[45]
	Test location	Dugway Proving Ground, Utah, USA
	Platforms involved	• AH-64D Apache • OH-58D Kiowa • Gray Eagle • Puma • Shadow • Hunter • RQ-11B Raven Also demonstrated at the exercise were controllers for the unmanned systems, including the Universal Ground Control Station, the mini-UGCS, and the One System Remote Video Terminal, or OSRVT.
	Experimental setup	Contractors acting as soldiers operated the UAV and passed control to AH-64D Apache and OH-58D Kiowa pilots. Mock attack on an abandoned

Test Name/ Date		Test Details
		tank. Additional tests were done using the Universal Ground Control Station which allowed control of multiple UAVs from a single ground station.[45]
	Results	The test demonstrated integration of Apache Block II and Kiowa Warrior helicopters, with Raven, Puma, Hunter, Shadow and Gray Eagle UAVs. Video was exchanged among all systems. With the use of the Universal Ground Control Station, the ability to control the UAS payloads of the larger aircraft was also demonstrated and the same aircraft operator and payload operator was able to fly a Shadow, a Gray Eagle and a Hunter aircraft consecutively, marking a huge milestone for UAS.[1]
	Level of Interoperability	Level 3

4.18 Kutta Manned Unmanned Teaming Kit (MUM-TK)

In 2012, Kutta Technologies launched their Manned Unmanned Teaming Kit (MUM-TK). This kit was developed with the US Air Force Aviation Applied Technology Directorate to expand the capabilities of manned aircraft by teaming them with their unmanned counterparts. "The modular MUM-TK facilitates the teaming of manned and unmanned assets. It is a light-weight kneeboard device, worn by the pilot during flight, designed to eliminate the repetitive motion strain required to navigate and control a typical UAS by providing an intuitive point-and-click interface through a resistive (supports gloved input) multi-touchpad." [3] Use of the kit facilitates Level 3 and 4 interoperability.

4.19 Manned Unmanned Operations Capability Development Laboratory (MUMO)

The Manned Unmanned Operations (MUMO) Capability Development Laboratory is a joint lab run by Bell Helicopter, AAI unmanned Aircraft Systems, and Textron Inc. It opened in December 2012 in Huntsville Alabama. It will enable "a software and hardware-in-the-loop (HWIL) development test capability using operationally relevant systems specific to manned unmanned teaming. This MUMO Capability Development Laboratory will serve as a research and development tool to support the U.S. Army Unmanned Aircraft Systems (UAS) vision and roadmap objectives for manned unmanned UAS operations in the near, mid and far-term timeframes…The lab will enable a high fidelity and interoperable MUMO simulation environment to support individual operator requirements for UAS and rotorcraft mission crew requirements."[46] The lab is equipped with Shadow Tactical UAS HWIL system integration lab (SIL), Kiowa Warrior OH-58D baseline simulation,[46] maintenance trainer for the Shadow unmanned aerial system (UAS), an iCommand suite, ground control station simulators and Gray Eagle/Shadow desktop trainers.[47]

4.20 Academic Research

A number of academic research projects showed up in the scientific and technical literature searches for manned unmanned teaming. These were reviewed and a total of five were determined to involve testing or simulation of manned unmanned teaming. These projects are briefly described below.

Strenzke, R., J. Uhrmann, et al. (2011).[48]	
Organizations involved	Aerospace Engineering Department, Institute of Flight Systems, Universität der Bundeswehr München
Nations involved	Germany
Experimental setup	Comprehensive evaluation experiments conducted in a research helicopter mission simulator.

Flaherty, S. R., T. Turpin, et al. (2006).[49]	
Organizations involved	• Aeroflightdynamics Directorate • U.S. Army Aviation and Missile Research, Development, and Engineering Center • Ames Research Center • Turpin Technologies
Nations involved	USA
Experimental setup	The simulation was designed to assess pilot-vehicle performance and workload associated with manned unmanned teaming. Seven experimental test pilots ran 24 missions controlling two UAVS and data was collected on accuracy and reaction times, number of target acquired, sensor efficiency and sensor utilization. Workload ratings, and simulator sickness symptoms were also recorded, and pilot interviewed were conducted.
Results	Subjective ratings and objective data supported a side by side display of independently controlled UAVs. Teaming with more than two UAVs may necessitate advances in display concepts due to limitations inherent in current cockpit design.
Level of interoperability	4

Shively, R. J., G. M. Neiswander, et al. (2011). [50]	
Organizations involved	Aeroflightdynamics Directorate (AMRDEC), U.S. Army
Nations involved	USA
Experimental setup	Simulation study of the effects of UAV delegation control in the cockpit. The study tested three levels of UAV control from the cockpit: UAV controlled with automated "playbook" control, UAV controlled with manual waypoint editing, and no UAV. Six subjects served as co-pilot in a helicopter during low level missions. The subject's primary task was target identification, and the secondary task was responding to communication queries.
Results	Use of "playbook" automation for UAV control reduced pilot workload and increased primary task performance with no impact on secondary task performance.
Follow-up planned	Future work will look at controlling multiple UAVs from the cockpit.
Level of interoperability	4

Gangl, S., B. Lettl, et al. (2013). [51]	
Organizations involved	Aerospace Engineering Department, Institute of Flight Systems, Universität der Bundeswehr München
Nations involved	Germany
Experimental setup	Testing of an automation concept that enables a pilot to manage more than one combat UAV. Laboratory prototype has been tested with operational personnel in a "human-in-the-loop full scenario simulation environment."
Follow-up planned	A full experimental design has been developed, no dates were provided for the conduct of the experiment.

Garcia, R. D., L. Barnes, et al. (2012). [52]	
Test description	This paper proposes a method to integrate UAVs into a manned/unmanned team through the use of 3D distributed flight control algorithms acting as wingmen for a manned aircraft. "The proposed work coordinates UAS members by utilizing artificial potential functions whose values are based on the state of the unmanned and manned assets including the desired formation, obstacles, task assignments, and perceived intentions. The overall unmanned team geometry is controlled using weighted potential fields. Individual UASs utilize fuzzy logic controllers for stability and navigation as well as a fuzzy reasoning engine for predicting the intent of surrounding aircrafts. Approaches are demonstrated in simulation using the commercial simulator X-Plane and controllers designed in Matlab/Simulink."

Garcia, R. D., L. Barnes, et al. (2012). [52]	
Organizations involved	University of South Florida, USA
Experimental setup	Staggered trail and right echelon formations and splinter group surveillance.

5 CONCLUSIONS

Thirteen (13) MUM-T programs, one lab devoted to researching MUM-T, and five MUM-T technologies currently in deployment have been identified. It was challenging to identify the many tests and programs involving manned-unmanned aircraft teaming, and it was equally challenging to pull together the details for each program and test. There has been a lot more work done in this field than expected, and the information is published in a scattered and incomplete manner. Several of the programs identified are ongoing and would be worth monitoring until their completion. The next MUSIC demonstration will occur in 2014 and will focus on mission expansion and improving the efficiency of UAV usage. [44] The Taranis testing component of SUAV(E) is currently undergoing much-delayed testing, and the results should be published sometime in the next year. [27] The German MUM-T project appears to be ongoing as well, and the results of their research are often published in the scientific literature. Finally, the Manned Unmanned Operations (MUMO) Capability Development Laboratory opened only a year ago, and can be expected to be conducting some interesting research in manned-unmanned teaming over the next few years. [46]

As shown in the listing of programs above, there are a few organizations leading the push for MUM-T: The US Army - particularly the Aviation Applied Technology Directorate - and DARPA are leading the way globally. Four major companies also stand out as being involved in many of the programs listed in this paper: Northrop Grumman, Lockheed Martin, Boeing, and AAI. For an up-to-date picture of MUM-T, all of these organizations should be monitored on a regular basis.

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7 APPENDICES

7.1 Methodology

7.1.1 Searches

A literature search was conducted in the research databases listed in Appendix 7.1.2. In order to identify as many relevant papers as possible, key concepts have been identified and defined using the most significant keywords. These keywords and concepts were combined in different ways, to cover all aspects of the problem.

At the request of the client, searches were restricted to 2003-2013. Literature searches were conducted in eight databases - Aerospace and High Technology, Scopus, NTIS, Inspec, Compendex, DTIC, Jane's[i] and NATO - which, combined, provide a comprehensive overview of the literature in this subject area. Searches for market research were conducted in Frost and Sullivan, Innovaro, IDC, Strategic Business Insights, Business Source Complete. Additional searches to identify projects not mentioned in published literature were conducted online using Google.

The following table lists the concepts included in each search as well as a sample of the search terms used to define each of them.

Table 12. Manned-unmanned teaming keywords

Manned	Unmanned	Teaming
• Piloted	• Drone • Raven • Puma • Shadow • Gray Eagle • UAV • UAS	• Link* • Interoperab* • Integrat* • Buddy • Unmanned wingman

Number of results: ~200

[i] Please note, the searches in Jane's were done by Renita Repsys at the DRDC library.

7.1.2 Sources

Online databases

- Scopus
- Aerospace and High Technology Database
- National Technical Information Service (NTIS)
- Inspec
- Compendex
- Jane's
- DTIC
- NATO
- Frost and Sullivan
- Innovaro
- IDC
- Strategic Business Insights
- Business Source Complete

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In addition to the references cited in the bibliography, the following papers were identified during searches and may be useful for additional information.

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