Defence Research and Development Canada | Recherche et développement pour la défense Canada

CAN UNCLASSIFIED

DRDC | RDDC
technologysciencetechnologie

# Cognitive task analysis for an unmanned aircraft system


G. Robert Arrabito
Ming Hou
DRDC – Toronto Research Centre

Simon Banbury
C3 Human Factors Consulting



**Defence Research and Development Canada**

**Reference Document**

DRDC-RDDC-2019-D041

May 2019


CAN UNCLASSIFIED

Canada

## IMPORTANT INFORMATIVE STATEMENTS

This document was reviewed for Controlled Goods by Defence Research and Development Canada (DRDC) using the Schedule to the *Defence Production Act*.

Disclaimer: This publication was prepared by Defence Research and Development Canada an agency of the Department of National Defence. The information contained in this publication has been derived and determined through best practice and adherence to the highest standards of responsible conduct of scientific research. This information is intended for the use of the Department of National Defence, the Canadian Armed Forces ("Canada") and Public Safety partners and, as permitted, may be shared with academia, industry, Canada's allies, and the public ("Third Parties"). Any use by, or any reliance on or decisions made based on this publication by Third Parties, are done at their own risk and responsibility. Canada does not assume any liability for any damages or losses which may arise from any use of, or reliance on, the publication.

Endorsement statement: This publication has been published by the Editorial Office of Defence Research and Development Canada, an agency of the Department of National Defence of Canada. Inquiries can be sent to: Publications.DRDC-RDDC@drdc-rddc.gc.ca.

© Her Majesty the Queen in Right of Canada (Department of National Defence), 2019

© Sa Majesté la Reine en droit du Canada (Ministère de la Défense nationale), 2019

# Abstract

The remote operation of an Unmanned Aircraft System (UAS) usually involves coordination between operators of the system in the Ground Control Station (GCS) and intelligence analysts who are in different geographical locations. The physical separation of these two teams can negatively influence collaboration and timely decision-making during time-sensitive operations. The integration of the UAS operators and the intelligence operators in the same location is expected to improve overall collaboration and decision making. The interface design process to support an integrated UAS operation starts by conducting a Cognitive Task Analysis (CTA) to reveal the cognitive processes that occur in the end users of the technology. This report carried out a CTA with suitable subject matter experts in the Canadian Armed Forces (CAF) to inform the identification of human machine interface requirements for a UAS GCS. A hybrid analysis technique was employed: mission function task analysis, goal-directed task analysis, and cognitive task analysis. The analysis focused on the critical situation awareness elements that are required by operators to make effective decisions within complex, time critical UAS missions.


# Significance to defence and security

Militaries rely on the use of an Unmanned Aircraft System (UAS) to provide Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) without putting a pilot's life at risk. The Royal Canadian Air Force (RCAF) will establish UAS cells at the Squadron level as part of the Joint Unmanned Surveillance and Target Acquisition System (JUSTAS) project, now called Remotely Piloted Aircraft System (RPAS). In order to explore this concept further and develop recommendations for GCS Human-Systems integration strategies, there is a requirement for the RCAF to conduct an analysis of the activities of these future UAS GCS operators. To support this effort, a Cognitive Task Analysis (CTA) was conducted for the anticipated UAS crew complement, based on a realistic operational scenario. This CTA lays the foundation for the design and development of a simulation/experimentation GCS that will allow RCAF UAS crews to maintain their operational skills and knowledge, and maintain readiness for the arrival of the new RCAF UAS fleet.

# Résumé

L'exploitation à distance d'un système d'aéronef sans pilote (UAS) nécessite habituellement la coordination entre les opérateurs du système au poste de contrôle au sol (PCS) et les analystes du renseignement à différents emplacements géographiques. La séparation physique entre ces deux équipes peut avoir une incidence négative sur la collaboration et la prise de décision en temps opportun lors d'opérations urgentes. Le regroupement au même endroit des opérateurs d'UAS et du renseignement devrait permettre d'améliorer globalement la collaboration et la prise de décision. Le processus de conception de l'interface à l'appui d'une opération d'UAS intégrée implique d'abord une analyse cognitive des tâches (ACT) pour déterminer les processus cognitifs chez les utilisateurs finaux de la technologie. Dans le cadre du présent rapport, des experts en la matière au sein des Forces armées canadiennes ont effectué une ACT afin de définir les exigences d'interface homme-machine pour le PCS d'un UAS. Une technique d'analyse hybride a été utilisée : analyse de missions, de fonctions et de tâches (MFTA); analyse des tâches guidée par les buts (GDTA). Cette analyse portait essentiellement sur les éléments de connaissance de la situation critique dont les opérateurs ont besoin pour prendre des décisions efficaces au  cours de missions d'UAS complexes et urgentes.


# Importance pour la défense et la sécurité

Les militaires se fient à l'utilisation d'un système d'aéronef sans pilote (UAS) pour répondre aux besoins en renseignement, surveillance, acquisition d'objectif et reconnaissance (ISTAR) sans mettre la vie d'un pilote en danger. L'Aviation royale canadienne (ARC) établira des cellules d'UAS au niveau de l'escadron dans le cadre du projet de Système interarmées de surveillance et d'acquisition d'objectifs au moyen de véhicules aériens sans pilote (JUSTAS), maintenant appelé système d'aéronef télépiloté (SATP). Afin d'étudier ce concept plus en profondeur et de formuler des recommandations concernant les stratégies d'intégration des systèmes humains des PCS, l'ARC doit analyser les activités des opérateurs des futurs PCS d'UAS. Pour appuyer cet effort, on a procédé à une analyse cognitive des tâches (ACT) de l'équipage d'UAS prévu en fonction d'un scénario opérationnel réaliste. Cette ACT établit les bases de la conception et de l'élaboration d'un PCS de simulation et d'expérimentation qui permettra aux équipages d'UAS de l'ARC de maintenir leurs connaissances et leurs compétences opérationnelles, de même que leur état de préparation pour l'arrivée de sa nouvelle flotte d'appareils.

# Table of contents

# List of figures

# List of tables

This page intentionally left blank.

# 1 Introduction

Unmanned Aircraft Systems (UASs) include the Unmanned Aircraft Vehicle (UAV), the Ground Control Station (GCS), and the human crews. UAS are a low-risk force multiplier for military operations, allowing militaries to perform a variety of missions that include Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) without putting a pilot's life at risk (Cook, 2007). UAS operations involve dynamic, real-time decision making, planning, post hoc re-planning, as well as team coordination (Gugerty, 2004). Typically, UAS operations have the Air Vehicle Operator (AVO) and Payload Operator (PO) located in the GCS while the Image Analysts (IMAs) and Electronic Warfare Analysts (EWAs) interpret the UAS sensor data from a different geographical location. Existing interfaces of UAVs provide little to no support for collaboration between distributed operators or for operators to collaborate with information consumers (da Silva, Scott, and Cummings, 2007).

Research has shown that it is difficult for distributed teams to have shared Situation Awareness (SA) (Bolstad, Cuevas, Gonzalez, Schneider, 2005; Wellens, 1993). The most widely cited definition of SA is "… the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley, 1995b, p. 36). Building upon this definition, shared SA is a reflection of how similar team members view a given situation.

For dynamic and fast-paced environments such as UAS operations, a high level of shared SA is always desirable. If good SA is coupled with good mental models, team members may be able to anticipate each other, provide support without explicit demands, thus reducing the need for unnecessary communications (Cannon-Bowers, Salas, and Converse, 1993). Since the interface of the UAS GCS is the primary communication link between the UAS and its human operators, a poorly designed GCS can significantly reduce safety and operational effectiveness of the UAS (da Silva, Scott, and Cummings, 2007).

To our knowledge, we are not aware of prior research in UAS operations investigating co-located and distributed teams. This research question was brought to our attention by the Royal Canadian Air Force (RCAF) who, in the process of procuring Canada's first UAS systems (Garrett-Rempel, 2015), tasked Defence Research and Development Canada (DRDC) – Toronto Research Centre to investigate whether there is an advantage to co-located teams compared to distributed teams for the operation of a Medium-Altitude, Long-Endurance (MALE) UAS (e.g., Predator). Specifically, the RCAF Joint Unmanned Surveillance and Target Acquisition System (JUSTAS) project, now called Remotely Piloted Aircraft System (RPAS), requires that the GCS includes an Air Vehicle Operator (AVO), a Payload Operator (PO), two Image Analysts (IMAs), and two Electronic Warfare Analysts (EWAs). By co-locating these crew members into a single GCS, it is expected that there would be improved individual and team SA, and an improvement to the timeliness and effectiveness of exploiting the information gained from the UAS sensors resulting in an overall increase in UAS mission effectiveness. Indeed, using our own current UAS GCS test bed (Covas-Smith, Grant, Hou, Joralmon, and Banbury, 2015; Hou, 2015), we conducted an exploratory study to evaluate GCS layouts for supporting individual and collective duties of a UAS crew during a combat mission. Preliminary results showed that a co-located GCS layout outperformed a distributed layout for crew communication, teamwork, and SA (Banbury, Pronovost, Pelletier, and Gagnon, 2017).

The research question has broader implications beyond the RCAF RPAS project given that in the future UASs are expected to become increasingly autonomous and, as a result, the organization of the UAS crews will likely need to evolve. In current UAS missions, it is usual to have multiple operators responsible for a single UAS platform. However, future UAS missions are expected to have a single operator in control of multiple UAS platforms (Cummings and Mitchell, 2006; da Silva, Scott, and Cummings, 2007) imposing unique and heavy workload demands on the operator (McCarley and Wickens, 2005). Furthermore, operators may also not have a complete understanding of how the UAS automation operates. The lack of understanding stems from the inherent challenges of complex systems, poor interface design, or inadequate training (Endsley, 1996). As a consequence, designers will be required to develop increasingly refined and robust methods to generate displays for the UAS GCS interface not only to support the operators (acting as a team) to accomplish their required tasks but also the display must understand the operator's decisions and share key information about the UAS capabilities authorities and responsibilities to the operator.

The interface design process for co-located UAS operations starts by conducting a Cognitive Task Analysis (CTA) to reveal the cognitive processes that occur in the end users of the technology. CTA is viewed as an important and necessary component of research and development for complex sociotechnical systems due to the high volumes of cognitive work involved (Hoffman and Militello, 2009; Hou, Banbury, and Burns, 2014). Specifically, the operating environment for UASs is complex and shares similarities with other complex socio-technical environments (Rasmussen, 1998). UAS operators must manage the sometimes competing goals and constraints of the aircraft, the mission, and the higher-level Command and Control (C2) structure (Hou, Kobierski, and Brown, 2007; Linegang, Stoner, Patterson, Seppelt, Hoffman, Crittendon, and Lee, 2006). Also, the operator interface and automation technologies are solutions to the more general problem of Human-Machine Interface (HMI) requirements (Hou, Banbury and Burns, 2014), and a catchall solution for all UASs and applications is unlikely (e.g., Adams, Humphrey, Goodrich, Cooper, Morse, Engh, and Rasmussen, 2009). Since the interface of the UAS GCS is the primary communication link between the UAS and its human operators, a poorly designed GCS can significantly reduce the safety and operational effectiveness of the UAS (da Silva, Scott, and Cummings, 2007).

The first step of the CTA process is for the human factors/ergonomics practitioner to find the right analytical tool for the task at hand and to apply it appropriately. A task has multiple facets and thus can be analyzed in many ways (e.g., actions, goals, and cognitive risks). There are many variants of CTA techniques employed (e.g., Chow, Kobierski, Coates, and Crebolder, 2006; Adams, Rogers, and Fisk, 2012; Lee and Kirlik, 2013; Schraagen, Chipman, and Shalin, 2000). However, traditional CTA approaches have limited applicability to futuristic systems because they generally require access to Subject Matter Experts (SMEs), documentation, and previous implementations from which to draw assumptions and expertise (Nehme, Scott, Cummings, and Furusho, 2006). Some tasks may not be suited to be analyzed by a specific method in which case a hybrid analytical technique is adopted that takes advantage of the strengths of two or more methods (Hou, Banbury, and Burns, 2014). Such a technique has been developed for futuristic UASs (Adams, Humphrey, Goodrich, Cooper, Morse, Engh, and Rasmussen, 2009; Almirao, da Silva, Scott, and Cummings, 2007; Nehme, Scott, Cummings, and Furusho, 2006).

The present report conducted a CTA for the individual and team of UAS operators performing mission crew tasks described by the RCAF RPAS project, which expands on a contract report conducted under Task Authorization 1 "Unmanned Aircraft System Information Flow and Cognitive Task Analyses" (Contract Number W7719-145238/001/TOR) for DRDC – Toronto Research Centre by Thales and

C3 Human Factors Consulting Inc. (Banbury, Baker, Tremblay, and Proulx, 2014); the present report builds on the contract report by providing a review of pertinent literature, enhancing the presentation of the CTA methodology, and summarizing the results of the CTA. Before describing the analysis approach, the report begins by presenting the case that Situation Awareness Oriented Design (SAOD) (Endsley and Jones, 2012) can provide an ideal design framework to optimize the design of the GCS interface, workstations and workspace layout in order to enhance crew SA and operational effectiveness (in terms of the speed and accuracy of decision making), reduce the likelihood of operator error, and provide an optimal level of mental workload for operators. The analytical techniques identified as most suitable for the UAS operations were used to develop a hybrid CTA methodology. The next section presents a hybrid analysis technique that was used to conduct the analysis activities on the mission crew roles of the RCAF's future UAS during ISTAR-related operations followed by a sample of results from its application. Subsequently, we discuss the effectiveness of the presented hybrid technique and how the findings can be used to guide the GCS interface design for the RCAF.

# 2 Selecting the analysis technique

This section describes the work undertaken to select the analysis technique for the UAS mission crew. The rationale for not analyzing any of the roles associated with the Launch and Recovery (LR) crew was to focus on aspects of UAS operations that were safety and mission critical, cognitively demanding on the operators, and would benefit most from innovative GCS design concepts. As such, the analysis of work activities associated with the mission crew was considered to be a higher priority than those of the LR crew.

## 2.1 Situation awareness as a design framework

Current UAS GCS concepts and interface designs have focused on the basic information elements relating to status of the UAS (e.g., flight information and health status) and its current tactical environment (e.g., tactical map with friendly and enemy force locations). Future analysis and design work will need to focus on more complex operator activities that require significant cognitive processing (e.g., decision making and problem solving). Given the complexity and dynamics of contemporary and future UAS operations, Endsley's dichotomy of the environment in terms of time and space from her widely-cited definition of SA (Endsley, 1995b) is of specific interest to our project. The way in which information is presented to the operator through the interface greatly influences SA by determining how much information can be acquired in the limited time available, how accurately it can be acquired, and the degree to which that information is compatible with the operator's SA needs (Endsley and Jones, 2012). The goal for the RCAF JUSTAS project is to identify information requirements for the GCS interface to support operators SA at all three levels (Perception, Comprehension, and Projection) without undue cognitive effort.

There is a large and growing corpus of knowledge relating to human factors challenges faced by UAS operators, particularly those issues relating to the cognitive vulnerabilities of UAS operators that can be leveraged to support the design of effective UAS GCS interface concepts. For example, Nisser and Westin (2006) identified several areas of human factors that will impact the operational effectiveness of future UASs (e.g., mental workload and vigilance, SA, teamwork, and decision making). Arrabito et al. (2010) performed a literature review and consulted with experienced UAS operators within the United States Air Force to identify human factors issues relating to controlling UASs. The key human factors issues for UASs that are highly automated (e.g., automated take-off and landing, and pre-programmed flight), were primarily related to problems pertaining to operator supervisory control such as maintaining vigilance, loss of SA, complacency (i.e., over-trusting the automation), skill degradation, and increased levels of mental workload. Building on this work, Banbury, Baker, Tremblay, and Proulx (2014) proposed 17 cognitive risks involved in the supervisory control of UAS. These reflect the aspects of cognitive functioning that are particularly vulnerable to the requirements of the UAS control such as mental activities (i.e., multi-tasking, decision making, trust, teamwork), cognitive capabilities (i.e., vigilance, skills/knowledge, workload, SA, temporal awareness), cognitive limitations (i.e., inattentional blindness, tunnel vision), and external stressors (i.e., time pressure, information overload, uncertainty, auditory distraction, complexity, high risk and broad consequences).

The cognitive risks associated with UAS mishaps are described within Endsley's model of SA (Endsley, 1995b). The importance of promoting SA in operators has proved to be a central issue for system design and training purposes in a wide range of work settings and Command and Control (C2) situations (Salmon, Stanton, Walker and Green, 2006). SA may be thought of as a collection of environmental and operator elements, knowledge types, abilities and skills (Durso and Gronlund, 1999). In the broadest possible sense, SA draws upon all the processes an operator brings to bear on a task such as their goals, perceptions, attention, dynamics, temporality, prediction, automaticity, processing, motor skills, pattern recognition, training, motivation, experience, encoding skill, knowledge acquisition, retrieval, storage, and execution (ESSAI project team, 2000).

Endsley's definition of SA has been developed into a theoretical model of SA (Endsley, 1995b). Endsley's model describes how SA "provides the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems" (Endsley, 1995a, p. 65). Although SA alone cannot guarantee successful decision making, SA does support the necessary input processes (e.g., cue recognition, situation assessment, and prediction) upon which good decisions are based (Artman, 2000).

Endsley (1995b) states that there are multiple factors that have been shown to influence the process of acquiring and maintaining SA. First, individuals may vary in their ability to acquire SA as a function of their cognitive abilities, which in turn may be influenced by innate abilities, experience and training. Second, individuals may possess certain preconceptions and objectives that can influence their perception and interpretation of their environment. Third, Endsley states that SA is also a function of the design of the system, both in terms of the degree to which the system provides the requisite information, and the format in which this information is provided. Finally, other features of the task environment, such as stress, workload, and system complexity, may also affect SA.

SA support can be accomplished using the Situation Awareness Oriented Design (SAOD) approach developed by Endsley and colleagues (Endsley and Jones, 2012) that focuses on improving human decision-making and performance through optimizing operator SA. The SAOD process is user-centered and derived from a detailed analysis of the goals, decisions, and SA requirements of the operator. This process has been successfully applied as a design philosophy for systems involving remote maintenance operations, medical systems, flexible manufacturing cells, and military command and control (Anderson and Bolstad, 2012).

There are three main components of SAOD: SA requirements analysis, SA-oriented design principles, and SA-oriented evaluation tools. SA requirements are defined as those dynamic information needs associated with the major goals or sub-goals of the operator when performing their work (as opposed to more static knowledge such as rules, procedures, and general system knowledge). SAOD includes a set of fifty design principles based on a theoretical model of the mechanisms and processes involved in acquiring and maintaining SA in dynamic complex systems (Endsley, 1995b). The SAOD principles are presented in Endsley and Jones (2012). These guidelines are focused on a model of human cognition involving dynamic switching between goal-driven and data-driven processing. As such, SAOD (Endsley and Jones, 2012) will be used as a suitable UAS GCS design framework to underpin the analysis method for the RCAF RPAS project.

## 2.2 Hybrid analytical technique

For our study, the selection of a particular analytical technique (or techniques) needs to fit within the context of UAS crew operations and support the requirements of the RCAF JUSTAS project. Namely, the technique(s) should support follow-on work to identify interface design requirements, training requirements, crewing requirements, military standards, etc. These constraints, along with the emphasis placed on cognition and SA, led us to develop six criteria for selecting the most appropriate analysis technique.

1. Situation awareness focused: The output of the analysis should identify the SA requirements for UAS crew members to perform individual and team tasks. This will support the development of information requirements for interface design, training requirements and crewing requirements.

2. Effort: The amount of effort required by the analysts to complete the analysis.

3. New system design: Since the RCAF does not currently operate UAS systems, the analysis aims to support the development of a new UAS system that meets Canadian requirements and not simply the improvement of an existing UAS.

4. Provides data for task modelling: In order to support client requirements, mainly interface and training requirements, the analysis must support task modelling. Task models will be used to determine which crew members perform which UAS tasks and which tasks can be performed by the system.

5. Facilitates the identification of cognitive risk: As outlined earlier in this report, UAS operations are increasingly associated with high levels of cognitive risk. The analysis should provide a model that readily identifies the cognitive limitations that could impair UAS processes and actions.

6. Military: The analysis is supported by military standards and has a track record of being used in the military domain.

Based on the above criteria, we could not find a single analysis technique in terms of both its appropriateness to the requirements of the RCAF RPAS project and its suitability for supporting SAOD (Endsley and Jones, 2012). We did, however, identify three suitable analytical techniques that can be combined to form a hybrid analytical technique that meets all the criteria: Mission, Function, and Task Analysis (MFTA), Goal-Directed Task Analysis (GDTA), and Cognitive Task Analysis (CTA). These methods have been selected to reflect approaches that have been used in complex decision making environments, and applicable to the analysis of the UAS operations described by the RCAF RPAS project. The goal of this study is not about the comparison of the three analytical methodologies but rather the information requirements identification using one technique or more techniques as a hybrid approach. The following paragraphs will describe the three methods selected and explain their suitability.

MFTA is a top down analysis framework developed for military environments (US Department of Defense, 2011). However, the approach and its concepts could be applied in other environments as well (Hou, Banbury, and Burns, 2014). The MFTA methodology begins with an analysis of high-level mission goals and use case development; a use case is a series of scenarios that occur in sequence in order to exercise primary functions of interest between the end-users and the system (Anton, Carter, Dagnino, Dempster, and Siege, 2001; Cockburn, 2000). Top level functions are prepared that are successively decomposed to a level that equates to an operator task. Next, the lowest level functions are allocated to the human operator, or to hardware, software or automation (i.e., the machine). Functions allocated to the person are referred to as operator tasks and analysis of these tasks completes the MFTA. At each stage, requirements can be extracted to inform the design of a system. Ideally, MFTA should be applied early in the design process as, by its nature, it tends to answer questions of scope and capability. In order to obtain detailed design information from this approach it should be augmented with other design methods (Darvill, Kumagai, and Youngson, 2006).

MFTA was used to analyze three tactical positions in the Operations Room of a Canadian Halifax Class frigate (Chow, Kobierski, Coates, and Crebolder, 2006). The use case combined the frigate's peacetime and wartime missions. MFTA produced a four-level hierarchy; the bottom level specified tasks to be performed by the three naval operators. The analysis could then be used to inform interface design and crew selection decisions.

In some cases MFTA is organized along a time base and not on an operator goal base. The ability of a system to support decision makers in successfully accomplishing their mission depends on how well the system supports their goals and SA requirements. However, only the GDTA method is SA-focused. GDTA, also known as Hierarchical Goal Analysis (HGA) (Hendy, Beevis, Lichacz, and Edwards, 2002) is an analytical technique built on Perceptual Control Theory (PCT) (Powers, 1973) that takes a control-theoretic view of human behaviour. As an aside, there is a special case of PCT called Layered Protocol Theory (LPT) (Farrell, Hollands, Taylor, and Gamble, 1999).

GDTA focuses on uncovering the SA requirements associated with a task domain (Endsley and Jones, 2012). The emphasis of GDTA is on information needs, and how that information must be used to support decision making in dynamic and complex environments. Three key steps are involved in the GDTA process: (1) identification of major goals and associated sub-goals for each decision maker; (2) the primary decision needed for each subgoal; and (3) the SA information requirements for making those decisions and carrying out each sub-goal. GDTA was applied to determine the SA requirements and goals for army brigade officers (Bolstad, Riley, Jones, and Endsley, 2002). Interviews were conducted with brigade officers for four positions. At the completion of the interviews, goal hierarchies with SA requirements were constructed and subsequently checked for accuracy by brigade officers. The analysis revealed similarities across positions and shared SA amongst officers. For example, all positions require knowledge of terrain information and officers share general information regarding troops, infrastructures and courses of action. The GDTA was a useful exercise to identify the SA requirements of army brigade officers and the information that needs to be shared between them.

GDTA is suited for extracting information for SA requirements in the context of UAS operations. The GDTA is also appropriate for informing the design of new systems. Unfortunately, the GDTA method is not very suitable with regards to the identification of cognitive risk and supporting task modelling activities. For these cases, the preferred method is the CTA technique as it focuses on the cognitive demands that are imposed on operators working in dynamic and complex environments. The goal of a CTA is to delineate the mental processes and skills needed to perform a task at high proficiency levels, and the changes in knowledge structure and processing as the skill develops over time. Whilst more traditional approaches emphasize the target performance desired, CTA addresses the knowledge structure and information processing strategies involved in task performance, and the underlying mental processes that give rise to errors. However, one drawback to the use of CTA is that it is extremely difficult to apply to a futuristic system for which no predecessor exists (Cummings and Guerlain, 2003; Scott, Sasangohar, and Cummings, 2009). In addition, CTA methods seek to model knowledge and cognition descriptively and as a result they often do not identify the key information the decision maker would ideally need to accomplish goals, nor do they identify how the decision maker integrates information to gain a good understanding of the situation.

CTA was previously applied to design simulated tasks for UAS operations (Gugerty, 2004). Both behavioural and performance interviews were conducted with US Air Force operators of the Predator UAS for the AVO, PO, and mission-planner positions for six mission stages (preflight, takeoff, enroute, data collection, return, and landing). In the behavioural interviews, operators were asked to describe the normal sequence of events for each stage of a mission, and to indicate which of these events involved high workload. Operators were also asked to describe what kind of things could go wrong at each mission stage. In the performance interviews, the investigators described realistic UAS mission scenarios using information from preflight briefings and mockups of UAS displays. The CTA analysis was used to design and develop a simulated task that represents the key cognitive demands of the UAS task.

The MFTA, GDTA, and CTA methods are all based on a functional modelling of the work domain rather than specific tasks for which the procedural sequence is well-known. This is an essential contribution to new system design. Although MFTA, GDTA, and CTA analysis techniques each have strengths and limitations, taken as a whole the strengths of one technique make up for the limitations of another and vice versa. Specifically, MFTA provides the level of rigour required for the design of a new military system and captures task flow and performance prediction information. GDTA provides the decision and SA requirements information required to identify opportunities for supporting UAS operators in their highly SA-dependent role. CTA provides a description of the cognitive risks experienced by operators to support the implementation of new interfaces. Given that the future UAS operator roles for the RCAF RPAS project are anticipated to be heavily reliant on cognitive capabilities, the analysis should be focused on identifying cognitive risks (as candidates for support for new technologies), particularly during mission phases heavily reliant on the acquisition and maintenance of SA and decision making.

# 3 Method

The CTA was conducted on the basis of a series of SME interviews relating to the UAS roles of AVO, PO, IMA, and EWA. Twelve SMEs served as participants. Of these, four were AVOs, two were POs, three were IMAs, and three were EWAs. All SMEs had similar ranks, operational experience and years served in the Canadian Armed Forces (CAF). The experience levels in our sample are representative of the population of UAS operators in the CAF. The conduct of the interviews was oriented towards capturing the critical decisions and SA requirements, as well as the flow of information between the UAS crew members based on the UAS tasks defined by the RCAF. All data gathered during the exercise fell within the definition of program evaluation rather than human experimentation, therefore, no DRDC Human Research Ethics Committee approval was required.

The hybrid analytical technique (MFTA, GDTA, and CTA) was carried out on the mission crew roles. A graphical representation of the process is presented in Figure 1. For the goal of *Understand Mission Tasking*, the two decisions have been identified: "What are the tasking requirements?" and "What is the Commander's intent?" These decisions are supported by several SA elements. The following subsections will elaborate on the three steps in more detail.

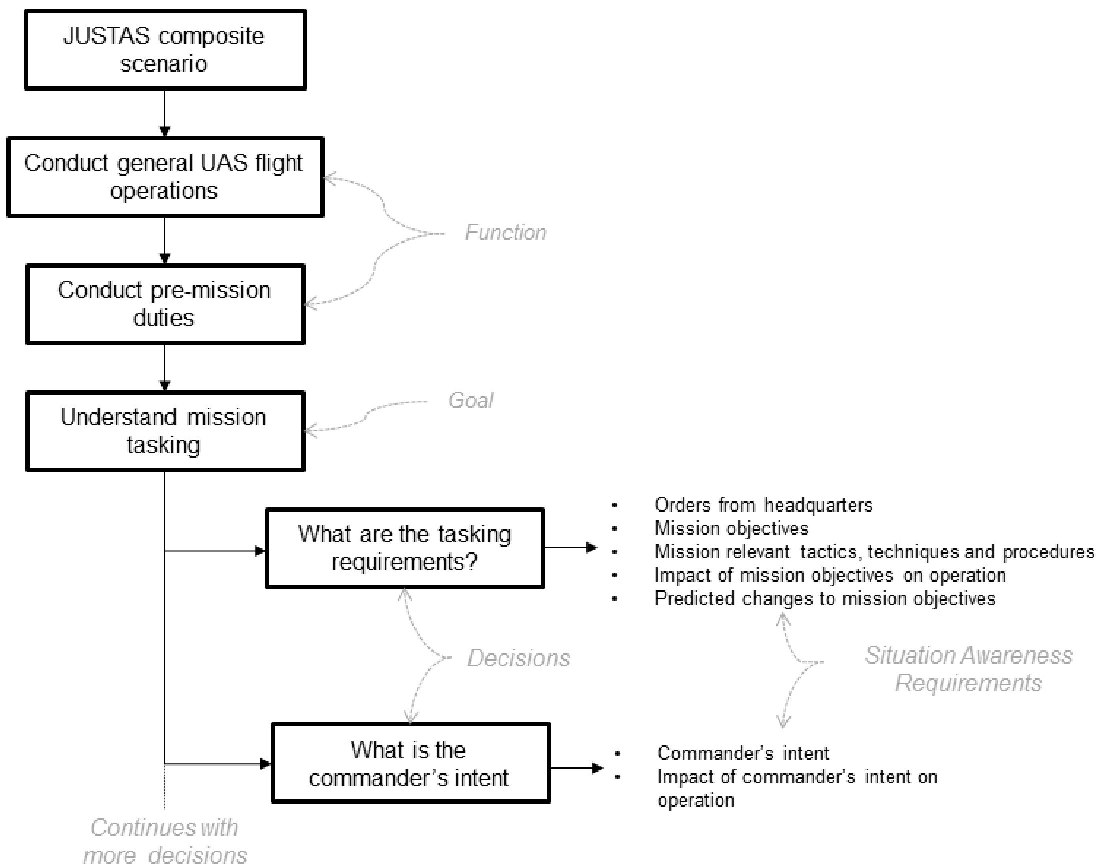


***Figure 1:*** *Example of Steps 1 and 2 of the hybrid MFTA-GDTA-CTA showing function, goal, decision and SA requirements levels of analysis for the RCAF RPAS use case (Adapted from Banbury, Baker, Proulx, and Tremblay, 2014, p. 57).*

## 3.1 Step 1—Mission and function analysis

### 3.1.1 Mission analysis

As described in MIL-STD-46855A (US Department of Defense, 2011), the mission analysis is a prerequisite for all of the subsequent analysis activities. The mission analysis sets out the boundaries of the subsequent function and goal analyses in terms of the scenarios, the operators, the anticipated system functions and features, and the likely environments in which the system will operate. With this in mind, we conducted the mission analysis by first carrying out a review of future UAS missions, including the operational requirements. We consulted internal RCAF documents that include the JUSTAS Statement of Operating Intent (SOI) and JUSTAS Concept of Operations (CONOPs). The JUSTAS SOI was produced by the JUSTAS Project Management Office (PMO) and describes how the RCAF intends to use the new MALE UAS. In general, the JUSTAS SOI identifies the intended roles, missions, tasks and usage of an aircraft type in sufficient detail to permit the engineering analysis and assessment of the proposed type design and allow selection of appropriate airworthiness standards by the Technical Airworthiness

Authority (TAA). The JUSTAS CONOPs was produced by the JUSTAS PMO and describes in more detail how the future UAS might be employed in the scenarios identified by the JUSTAS SOI. This document is intended to inform the procurement, integration and further development of a UAS capability to enhance CAF domestic and expeditionary capabilities. (As a reminder, the JUSTAS project is now called the Remotely Piloted Aircraft System (RPAS) project.)

Following the selection of the operational requirements of interest, a use case was developed based on the JUSTAS CONOPs that states at a high level how operators will interact with the future UAS (Kobierski, 2013a). Specifically, the use case consists of a foreign operation conducted from a Main Operating Base in Canada. The UAS initially executes a border surveillance mission followed by a reconnaissance mission. Subsequently, the UAS is re-tasked to provide security and escort of a convoy which comes under attack. The UAS crew acquires the enemy that has fired on the unarmed convoy, engages this target and finally conducts a combat assessment prior to returning to base. Figure 2 illustrates the UAS flight pattern during the target engagement mission segment of the use case.

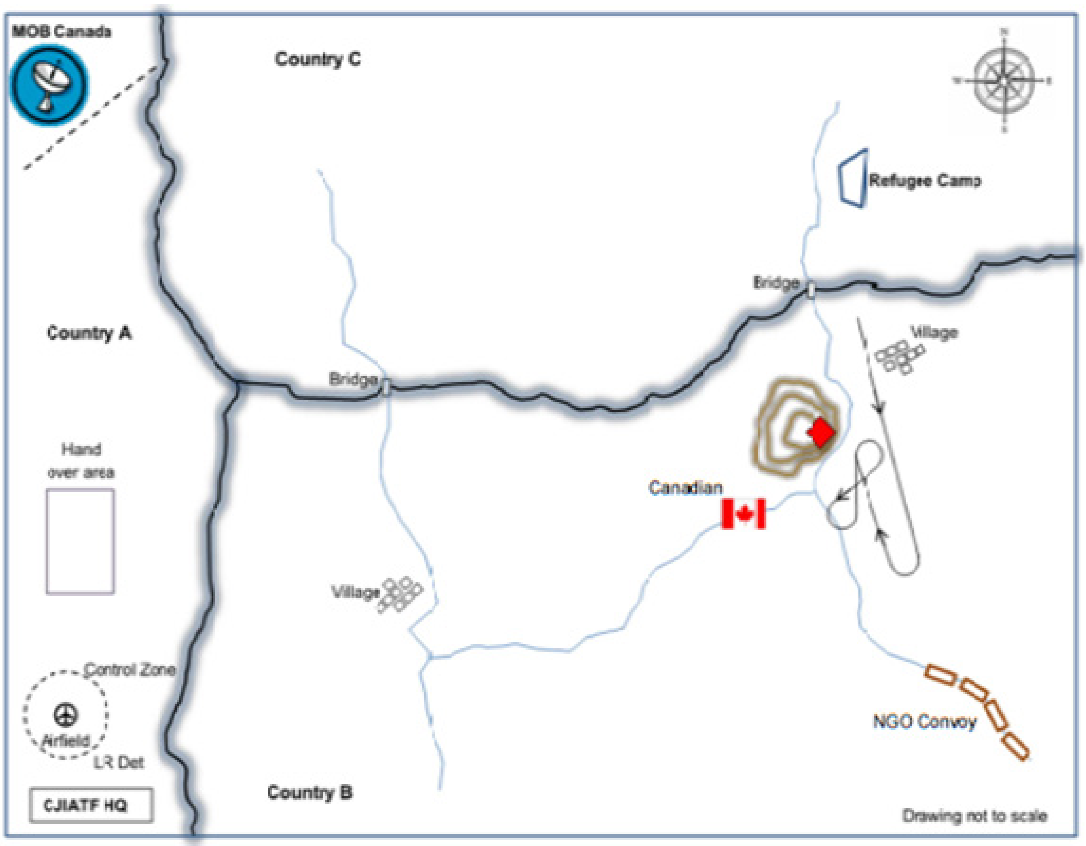


***Figure 2:*** *UAS route during target engagement (Banbury, Baker, Tremblay, and Proulx, 2014, p. 66).*

The operators of the future UAS were also identified and characterized. This work included assumptions relating to the physical, cognitive, and experience (including training) requirements of potential operators of the system (Kobierski, 2013b). Basic equipment (including their capabilities) associated with the GCS was identified (Kobierski, 2013c). Top-level requirements that must be met in order to achieve the mission objectives were also identified. In addition, basic *what if* contingencies for the mission scenarios (e.g., actions undertaken in the event of a system failure) were also described (Kobierski, 2013c). The main data products of the mission analysis are therefore the use case and the target audience description. This provides a foundation upon which to conduct the function and goal analyses and to underpin the subsequent activities relating to the high-level design and validation of the GCS interface, workstation and workspace concepts.

### 3.1.2 Function analysis

The objective of the function analysis is to identify and describe the major activities (i.e., functions) that must be performed to satisfy the mission requirements and objectives (as identified by the Mission Analysis) (US Department of Defense, 2011). Functions are broad categories of activities performed within a scenario, and all functions can be broken down or divided into more detailed functions. To that end, the use case (Kobierski, 2013a) was divided into a series of distinct sections, each with its own hierarchy of functions, but related to each other in a logical and temporal sequence. Using mission objectives described in the use case as a starting point, a functional decomposition refined these objectives to the point at which a hierarchy of specific operator functions and sub-functions could be identified; each of the high-level functions was decomposed through to the second level in the Function Analysis to capture the sub-functions that support the UAS crew's accomplishment of the use case. This functional decomposition was developed from a combination of document review and interviews with SMEs. The identification of the mission related functions provides the operational context for deriving the SA requirements used by the UAS crew to assist them in making the decisions that facilitate the achievement of their goals.

## 3.2 Step 2—Goal, decision and situation awareness requirements analysis

### 3.2.1 Goal analysis

The next step of the analysis was to connect the high-level functions resulting from the initial phases of the MFTA to the goal-oriented analysis of GDTA. Goals are higher-order objectives essential to successful performance of the high-level functions and mission objectives. The transition from a scenario-specific function to a goal (and associated sub-goals) allows the continuation of the GDTA procedure. As such, the goals that must be reached in order to complete each second-level function were identified using goal flow diagrams. These diagrams are similar to the function (or task) flow diagrams that represent the sequences of activities undertaken by operators in the MFTA (US Department of Defense, 2011). The goals identified for each second-level function were arranged both logically and chronologically. These types of diagrams are particularly useful for representing and reviewing the results of the mission decomposition with SMEs; their graphical nature makes them easy to understand and associate with the operational environment. Simple logical connectors "AND" and "OR" were used to indicate whether a group of goals must be performed concurrently (i.e., AND) or sequentially (i.e., OR) to complete each second-level mission function. Goal flow diagrams were developed to illustrate the temporal sequence of the goals in accordance with the use case (Kobierski, 2013a). The complete set of goal flow diagrams is presented elsewhere (Banbury, S., Baker, K., Tremblay, S., and Proulx, R., 2014).

### 3.2.2 Decision analysis

Within the GDTA procedure, the next step involves identifying the decisions that must be made by the operator in order to achieve a particular goal. Decisions are associated with a specific goal, though a similar decision may occur in more than one goal. Decisions are essentially the questions the decision maker must answer in order to achieve a specified goal. As such, the decisions that must be made in order to achieve each goal of the mission analysis were identified. These include decision identification, decision allocation, decision flow diagrams, and decision ladders.

Each decision is represented in the form of a question (e.g., "Is the Synthetic Aperture Radar (SAR) providing usable imagery?"), and the subsequent SA requirements provide the information needed to answer the question. Questions that can be answered *yes/no* are not typically considered appropriately worded decisions in a GDTA (Endsley and Jones, 2012).

Similar to the function allocation component of the MFTA (US Department of Defense, 2011), the decision allocation component of the analysis identified the UAS role(s) involved in the decision making process for each decision identified in the analysis. Six UAS crew members were allocated against each decision. These six roles include the AVO, PO, two IMAs and two EWAs. The two IMA roles were divided into an analyst role, IMA-A, that focuses on real-time imagery interpretation and a reporter role, IMA-R, that focuses on imagery related intelligence production and dissemination. The two EW roles were similarly divided into analyst, EW-A, and reporter, EW-R.

Decision flow diagrams are similar to the function/goal diagrams. The decisions pertaining to each goal were arranged both logically and chronologically using simple logical connectors "AND" and "OR" to indicate whether a group of decisions must be performed concurrently (i.e., AND) or sequentially (i.e., OR) to achieve each goal. The aforementioned goal flow diagrams were subsequently decomposed to illustrate the sequencing of decisions required to achieve each individual goal. The complete set of decision flow diagrams is presented elsewhere (Banbury, Baker, Tremblay, and Proulx, 2014).

In order to obtain a detailed understanding of what information and knowledge is needed to support the operator's decision-making process, decision ladders were constructed for each decision identified by the analysis. Decision ladders are modelling tools that capture the states of knowledge and information-processing activities necessary to reach a decision (Rasmussen, 1974). For example, we provide the decision ladder for the decision "Is the synthetic aperture radar providing usable imagery?" As illustrated in Figure 3, the decision ladder contains two different types of nodes. The boxes represent data-processing activities (and each UAS crew role involved) and the italicized text between them represents the states of knowledge resulting from those data-processing activities. The left side of the decision ladder represents the observation of the current system state and the right side of the decision ladder represents the planning and execution of tasks and procedures to achieve a target system state (which in turn might fulfill, or partly fulfill, a goal). The actual decision is itself represented at the top of the decision ladder.

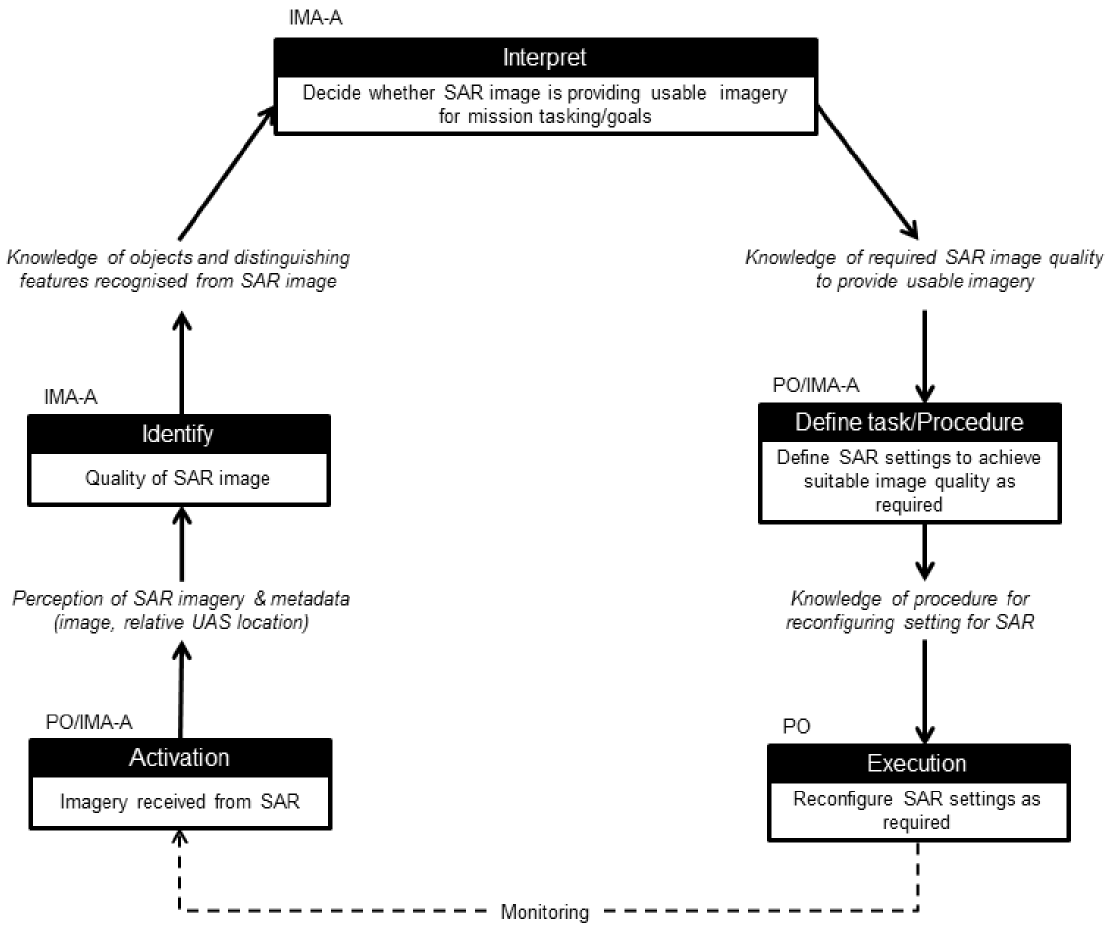


***Figure 3:*** *Example decision ladder for the decision "Is the synthetic aperture radar providing usable imagery?" (Adapted from Banbury, Baker, Tremblay, and Proulx, 2014, p. 60)*

The decision ladder maps the structure of a decision-making process so that the states of knowledge that must be achieved to make the decision can be understood. As such, decision ladders are used to perform SA requirements analysis. The objective of the SA requirements analysis is to identify the information (i.e., SA elements) that UAS operators and crew must possess in order to successfully make a particular decision. For each decision, the SA requirements required to make the decision were identified. Then, the complete list of SA requirements is compiled in terms of the Mission, Enemy, Terrain, Time, Troops and Civilians (METT-TC) categorization. METT-TC is a military classification scheme used by the United States Department of Defense and identifies the highest priority variables that should be analyzed during the planning phase of any operation (US Army, 2012). The SA requirements were further classified according to Endsley's (1995b) three levels of SA: Level 1 (Perception), Level 2 (Comprehension) and Level 3 (Projection).

## 3.3 Step 3—Cognitive risk analysis

### 3.3.1 Identify critical decisions

The final step of the analysis was to identify the critical decisions that would be analyzed in more detail with regards to their cognitive risk. Based on the method for identifying critical tasks that is specified in MIL-STD-46855A (US Department of Defense, 2011), each decision was identified as critical if one of more of the following criteria were considered to be an important concern with respect to this specific decision: safety, mission completion or effectiveness, cost, efficiency, or system reliability.

# 4 Results

Each step of the hybrid analytical technique (MFTA-GDTA-CTA) generates results that depend on the outcomes of the previous steps. The first step, the MFTA, results in a set of functions that would allow a UAS and its crew to successfully complete missions. Next, goal analysis identifies the goals that need to be met for each function to be successful. Decision analysis identifies the crew members and the decisions they need to make in order to meet the previously identified goals. SA requirements analysis identifies the information that the UAS crew members need in order to make those decisions. Finally the cognitive risk analysis determines why decisions may be critical and the risks associated with each decision. In total, the hybrid analysis approach identified 26 functions, 85 goals, 339 decisions, and 145 SA requirements for the UAS operators and crew. These data were combined from the 12 participants by having certain SMEs who gave their opinions based on their own individual expertise areas first followed by other SMEs who reviewed the previous comments and gave their own feedback. This process resembled a consensus approach and was adopted based on participant availability. Due to the large amount of information created by the hybrid technique, this section provides only a subset of the results from the MFTA, GDTA, and CTA steps to demonstrate the hybrid technique. The full list of results is provided elsewhere (Banbury, Baker, Tremblay, and Proulx, 2014).

The mission and function analysis resulted in six first-level functions for successful UAS operations based on the use case (Kobierski, 2013a): (1) Conduct general UAS flight operations, (2) Conduct surveillance, (3) Conduct reconnaissance, (4) Conduct security and escort, (5) Conduct target acquisition, and (6) Conduct target engagement. Each of these first-level functions was decomposed into a set of second-level functions that are required to complete the first-level function. All of the first- and second-level functions identified for RPAS UAS operations are presented in Table 1.

***Table 1:*** *First and second level function decomposition of mission and function analysis.*

| First level function | Second level function |
|---|---|
| 1. Conduct general UAS flight operations | 1. Conduct pre-mission duties<br>2. Conduct UAV hand-over<br>3. Conduct manage UAV flight<br>4. Manage UAV payload<br>5. Maintain tactical awareness<br>6. Manage communications<br>7. Conduct reporting<br>8. Manage re-tasking orders<br>9. Manage system faults/failures<br>10. Conduct post-mission duties |
| 2. Conduct surveillance | 1. Collect imagery<br>2. Collect EW/SIGINT<br>3. Generate and disseminate surveillance data products |
| 3. Conduct reconnaissance | 1. Conduct reconnoitre<br>2. Collect EW/SIGINT<br>3. Generate and disseminate reconnaissance data product |

| First level function | Second level function |
|---|---|
| 4. Conduct security and escort | 1. Rendezvous with Blue Force<br>2. Collect imagery<br>3. Collect EW/SIGINT<br>4. Provide Blue Force over-watch |
| 5. Conduct target acquisition | 1. Establish contact track<br>2. Manage contact<br>3. Maintain contact track |
| 6. Conduct target engagement | 1. Conduct direct attack<br>2. Conduct call for fire<br>3. Conduct combat assessment |

The goal, decision, and SA requirements analysis resulted in the identification of the UAS crew members, their goals, decisions, flow diagrams, and SA requirements for each first- and second-level function identified in the mission and function analysis. For example, Function 5.1 “Establish contact track” (Banbury, S., Baker, K., Tremblay, S., and Proulx, R., 2014) has a goal to localize a contact that requires the PO, IMA, and EWA to make a decision on the position of a contact. This decision requires SA on the locations of the enemy forces, the UAS, friendly forces, non-government organizations, and civilians as well as SA on the contact acquired by the UAS system, UAS imagery, and UAS EW data. Function 5.1 was identified to have four goals that require a total of 19 decisions, with each goal having between three and six decisions.

This stage of the CTA analysis also resulted in function, goal and decision flow diagrams. These diagrams outline the temporal sequence that the functions, goals, and decisions occur. Figure 4 shows the flow diagram for the first- and second-level functions. Figure 5 shows the goal and decision flow for the example function 5.1 “Establish contact track” as well as the operators that make each decision. Decision ladders were also generated for the functions prioritized by the RCAF RPAS project: surveillance, reconnaissance, security and escort, target acquisition, and target engagement. An example decision ladder for decision “Is the synthetic aperture radar providing usable imagery?” is shown in Figure 3.

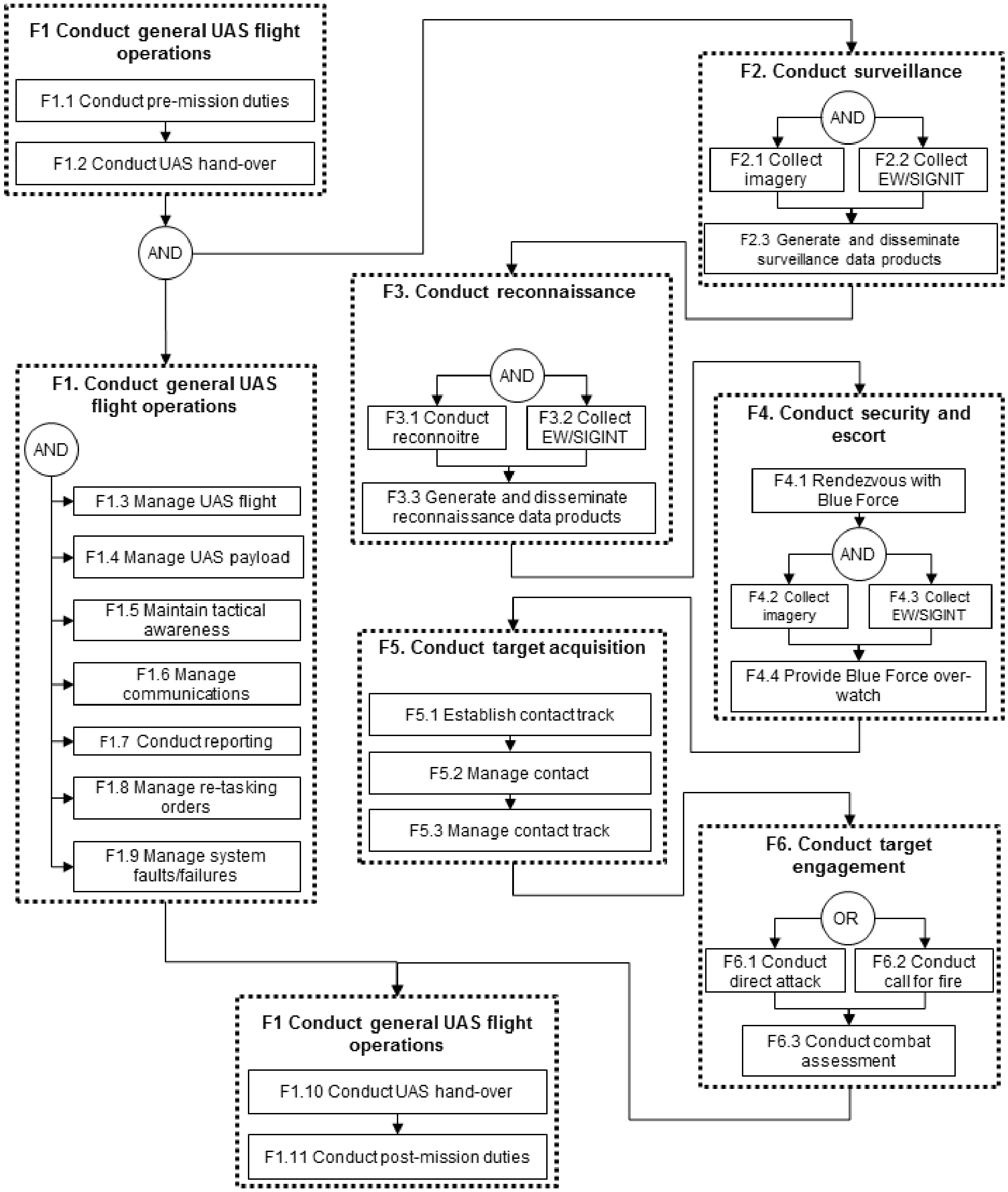


***Figure 4:*** *Function flow diagram (Adapted from Banbury, Baker, Tremblay, and Proulx, 2014, p. 219).*

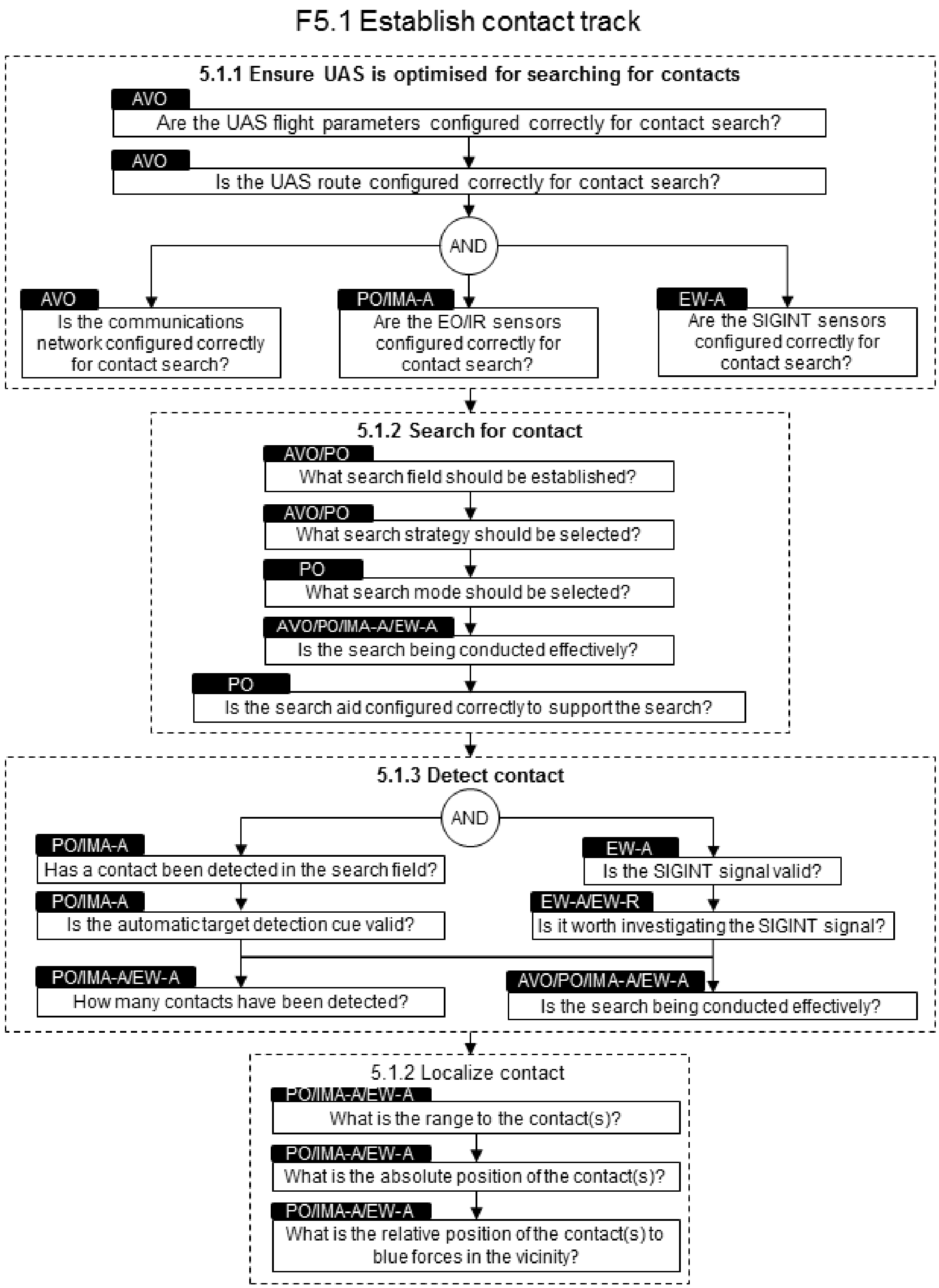


***Figure 5:*** *Function 5.1 "Establish contact track" goal and decision flow diagram (Adapted from Banbury, Baker, Tremblay, and Proulx, 2014, p. 245).*

In addition to identification of the SA requirements for each decision, this analysis found that all UAS crew roles routinely engage in SA-intensive tasks insofar as they are required to comprehend the situation and anticipate future consequences. However, the roles require SA of different time horizons. For example, the image and EW analysts are more concerned with longer-term issues such as intelligence-related mission goals, whereas the AVO and PO are concerned with maneuvering the UAS within shorter-time windows. The SA requirements attributed to each decision identified in the analysis are presented in Annex B. The SA requirements are organized in terms of both METT-TC classification and Endsley's (1995b) three levels of SA (i.e., perception, comprehension, and projection).

The cognitive risk analysis resulted in the identification of which decisions were critical, why they were critical, and the cognitive risks associated with each decision. For example, the decision "What is the absolute position of the contact(s)?" is critical for mission completion and/or effectiveness and there are cognitive risks for SA, skills and knowledge, time pressure, and uncertainty. Other decisions were identified as critical for UAS efficiency, safety, system reliability, etc. Cognitive risks for other decisions include complexity, teamwork, multi-tasking, information overload, and high risk and broad consequences. The critical decisions, and their associated cognitive risks, identified in the analysis are presented in Annex B.

# 5 Discussion

Interface design is a complex process that begins with designers to identify system constraints and goals. This report described the CTA that derived information requirements and critical decisions for a UAS crew including both UAS operators and intelligence analysts in support of the RCAF RPAS project. The CTA was based on a hybrid approach that involved a combination of three analysis techniques: mission and function analysis (from the MFTA), goal, decision and SA requirements analysis (from the GDTA), and cognitive risk analysis (from the MFTA and CTA). Critical decisions were analyzed in terms of the information required to make them. The information was categorized in terms of source (e.g., the threat, system status information, information from other units, and outside world situation) and time constraints on the collection, interpretation and actions required. Decisions were then analyzed for potential for assistance through the recall of stored information or rules, manipulation or analysis, or the application of more advanced techniques of decision.

The hybrid analysis identified 26 functions, 85 goals, 339 decisions, and 145 SA requirements across the ISTAR-related mission developed for the RCAF RPAS project (Kobierski, 2013a). We did not compare the hybrid technique with other techniques. The selection of the three analytical techniques that comprised the hybrid approach was based on the analyst's knowledge and experience using the techniques. As the RPAS project required to identify information requirements for the GCS interface to support operators SA at all three levels, we found that these techniques can offer most of the requirements needed to identify the SA requirements. We believe, in the absence of real data or comparable studies, this hybrid approach can capture the information requirements critical information requirements of UAS crew members.

The results of the hybrid approach were communicated to the RCAF for follow-on work in support of the RPAS project that include:

- UAS GCS HMI Design requirements of the GCS interface (Banbury, Pelletier, Baker, Tremblay, and Proulx, 2014);
- Operator training needs analysis and performance modelling (Banbury, Forbes, Pronovost, Tremblay, and Proulx, 2014; Banbury, Baker, Pronovost, and Proulx, 2015);
- Anticipated operator competency development (Banbury, Pelletier, Baker, Tremblay, and Proulx, 2015);
- Baseline requirements for the investigations of a Testbed for Integrated Ground Control Station Experimentation and Rehearsal (TIGER) capabilities (Banbury, Pelletier, Baker, Tremblay, and Proulx, 2015; Banbury, Pelletier, and Baker, 2015);
- TIGER workstation configuration layout comparison (Banbury, Pronovost, Pelletier, and Gagnon, 2017);
- High-level proposed integrated timeline for development of RPAS concept, operator training, and airworthiness certification (Proulx, Banbury, and Pronovost, 2015); and
- Design requirements of Authority Pathway as an intelligent decision aid for Weapon Engagement (Banbury, and Pronovost, 2016; Banbury, Pelletier, and Gagnon, 2016).

A contribution of the present study is that it supports the concept of employing a hybrid analysis (MFTA, GDTA, and CTA) to inform the design and systems engineering process of a first-of-a-kind co-located UAS team. When MFTA, GDTA, and CTA are combined, the result is the ability to more readily integrate the results of the three analytical techniques (Hou et al., 2014). This is the first application of these techniques in concert to inform the development of a co-located GCS and the associated operator interface.

Future studies will need to determine how a co-located crew be organized into a room-scale workspace layout that facilitates successful completion of the mission objectives. The next step, therefore, is to identify the interface display, interaction and feedback requirements to support the SA requirements identified by the hybrid analysis.

# 6 Conclusions

Military organizations rely on UASs to perform ISTAR missions. The distributed layout of operators and intelligence analysts warranted a need to improve the human-UAS interaction. Within the context of the RCAF JUSTAS CONOPS and the use case (Kobierski, 2013a), a hybrid analysis technique comprising of MFTA, GDTA, and CTA was performed with suitable SMEs. Information requirements and critical decisions were derived for a UAS crew including both UAS operators and intelligence analysts. Numerous critical decisions and SA elements were analyzed in terms of the information required to make them effectively within complex, time pressured UAS missions.

The nature of the analysis methodology described in this report allowed the identification of SA requirements associated with each goal (and decision) to be made independently of the physical tasks that must be completed in order to accomplish the goal. Consequently, the analysis was not constrained by the technological solutions that are currently available or by the timelines that would be associated with completing physical tasks. Without these constraints, the analysis was able to provide interface design recommendations and the freedom to address SA requirements through workstation design concepts. The analysis was an essential prerequisite for subsequent work to support the RPAS project by Thales and C3 Human Factors Consulting Inc. as part of the Human-Technology Interaction standing offer (Contract Number W7719-145238/001/TOR; see Annex B).

# References


Adams, A. E., Rogers, W. A., and Fisk, A. D. (2012). Choosing the right task analysis tool. *Ergonomics in Design*, 20, pp. 4–10.

Adams, J. A., Humphrey, C. M., Goodrich, M. A., Cooper, J. L., Morse, B. S., Engh, C., and Rasmussen, N. (2009). Cognitive task analysis for developing unmanned aerial vehicle wilderness search support. *Journal of Cognitive Engineering and Decision Making*, 3, pp. 1–26.

Almirao, F. M., da Silva, F. B., Scott, S. D., and Cummings, M. L. (2007). Designing decisions and collaboration support technology for operators in multi-UAV operations teams. (Report No. HAL2007-12). Cambridge, MA: Humans and Automation Laboratory, Massachusetts Institute of Technology.

Anderson, T. J., and Bolstad, C. A. (2012). Situation awareness-oriented design and the CDC Biophusion center. Symposium on Human Factors in Health Care. Baltimore, MD: Human Factors and Ergonomics Society.

Anton, A. I., Carter, R. A., Dagnino, A., Dempster, J. H., and Siege, D. F. (2001). Deriving goals from a use-case based requirements specification. *Requirements Engineering*, 6, pp. 63–73.

Arrabito, G. R., Ho, G., Lambert, A., Rutley, M., Keillor, J., Chiu, A., Au, H., and Hou, M. (2010). Human factors issues for controlling uninhabited aerial vehicles: Preliminary findings in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System. Defence R&D Canada – Toronto, Technical Report, DRDC Toronto TR-2009-043.

Artman, H. (2000). Team situation assessment and information distribution. *Ergonomics*, 43, pp. 1111–1128.

Banbury, S., Baker, K., Pronovost, S., and Proulx, R. (2015). TA7: Unmanned aircraft system operator task refinement and performance modeling. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2015-C143.

Banbury, S., Baker, K., Tremblay, S., and Proulx, R. (2014). TA1: Unmanned air system operator information flow and cognitive task analyses. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2014-C307.

Banbury, S., Forbes, K., Pronovost, S., Tremblay, S., and Proulx, R. (2014). TA3: Ground control station training needs analysis and performance modeling. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2014-C211.

Banbury, S., Pelletier, S., and Baker, K. (2015). TA8: Unmanned aircraft system ground control station human machine interface and workspace refinement, and human factors engineering trial support. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2015-C144.

Banbury, S., Pelletier, S., Baker, K., Tremblay, S., and Proulx, R. (2014). TA2: Ground control station design concepts and human factors engineering test plan. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2014-C205.

Banbury, S., Pelletier, S., Baker, K., Tremblay, S., and Proulx, R. (2015). TA6: Development of an anticipatory competency analysis for JUSTAS. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2015-C142.

Banbury, S., Pelletier, S., and Gagnon, J. F. (2016). TA10: Human factors support to evaluation of ground control station workspace options. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2016-C196.

Banbury, S., and Pronovost, S. (2016). TA9: Task network modeling to support intelligent adaptive system integration within UAS ground control station. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2016-C197.

Banbury, S., Pronovost, S., Pelletier, S., and Gagnon, J. F. (2017). TA11: Human factors support to evaluation of ground control station workspace options (Part II). Defence Research and Development Canada, Contract Report, DRDC-RDDC-2017-C176.

Banbury, S., Tremblay, S., and Gagnon, J. F. (2014). TA4: Human factors support to unmanned aircraft system ground control station experimental trial at Air Force Research Laboratory. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2014-C213.

Bolstad, C. A., Cuevas, H., Gonzalez, C., and Schneider, M. (2005). Modeling shared situation awareness. In *Proceedings of the 14th Conference on Behavior Representation in Modeling and Simulation (BRIMS)*. Los Angeles, CA: Simulation Interoperability Standards Organization.

Bolstad, C. A., Riley, J. M., Jones, D. G., and Endsley, M. R. (2002). Using goal directed task analysis with army brigade officer teams. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting,* pp. 472–476. Los Angeles, CA: SAGE Publications.

Cannon-Bowers, J. A., Salas, E., and Converse, S. A. (1993). Shared mental models in expert team decision making. In N. J. Castellan, Jr. (Ed.), Individual and group decision making: Current issues, pp. 221–246. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chow, R., Kobierski, B., Coates, C., and Crebolder, J. (2006). Applied comparison between hierarchical goal analysis and mission, function and task analysis. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting,* pp. 520–524. Los Angeles, CA: SAGE Publications.

Cockburn, A. (2000). Writing effective use cases. New York, NY: Addison-Wesley.

Cook, K. L. (2007). The silent force multiplier: The history and roles of UAVs in warfare. In *IEEE 2007 Aerospace Conference*, pp. 1–7. New York, NY: IEEE Press.

Covas-Smith, C. M., Grant, S. C., Hou, M., Joralmon, D. Q., and Banbury, S. (2015). Development of a testbed for integrated ground control station experimentation and rehearsal (TIGER): Training remotely piloted aircraft operations and data exploitation. In *Unmanned Systems*, pp. 1–11. Association for Unmanned Vehicle Systems International (AUVSI).

Cummings, M. L., and Guerlain, S. (2003). The tactical tomahawk conundrum: Designing decision support systems for revolutionary domains. In *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, pp. 1583–1588. Washington, DC: IEEE.

Cummings, M. L., and Mitchell, P. J. (2006). Automated scheduling decision support for supervisory control of multiple UAVs. *Journal of Aerospace Computing Information, and Communication*, 3, pp. 294–308.

da Silva, F. B., Scott, S. D., and Cummings, M. L. (2007). Design methodology for unmanned aerial vehicle (UAV) team coordination (Report No. HAL2007-05). Cambridge, MA: Humans and Automation Laboratory, Massachusetts Institute of Technology.

Darvill, D., Kumagai, J., and Youngson, G. (2006). Requirements analysis methods for complex systems. Defence R&D Canada – Valcartier, Contract Report, DRDC Valcartier CR-2005-076.

Durso, F. T., and Gronlund, S. D. (1999). Situation awareness. In F. T. Durso, R. S. Nickerson, R. W. Schvaneveldt, S. T. Dumais, D. S. Lindays, and M. T. H. Chi (Eds.), Handbook of applied cognition, pp. 283–314. New York, NY: Wiley.

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors*, 37, pp. 65–84.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37, pp. 32–64.

Endsley, M. R. (1996). Automation and situation awareness. In R. Parasuraman, and M. Mouloua (Eds.), Automation and human performance, pp. 163–181. Mahwah, NJ: Lawrence Erlbaum Press.

Endsley, M. R., and Jones, D. G. (2012). Designing for situation awareness: An approach to user-centered design (2nd ed.). Boca Raton, FL: CRC Press.

ESSAI project team (2000). Orientation on situation awareness and crisis management (Report No. NLR-TR-2000-668). Amsterdam, The Netherlands: National Aerospace Laboratory NLR.

Farrell, P. S. E., Hollands, J. G., Taylor, M. M., and Gamble, H. D. (1999). Perceptual control and layered protocols in interface design: I. Fundamental concepts. *International Journal of Human-Computer Studies*, 50, pp. 489–520.

Garrett-Rempel, D. (2015). Will JUSTAS Prevail? Procuring a UAS Capability for Canada. *The Royal Canadian Air Force Journal*, 4, pp. 19–31. http://www.rcaf-arc.forces.gc.ca/en/cf-aerospace-warfare-centre/elibrary/journal/2015-vol4-iss1-05-will-justas-prevail.page (Accessed August 28, 2017).

Gugerty, L. (2004). Using cognitive task analysis to design multiple synthetic tasks for uninhabited aerial vehicle operation. In S. G. Schiflett, L. R., Eilliott, E., Salas, and M. D. Coovert (Eds.), Scaled worlds: Development, validation and applications, pp. 240–262. Aldershot, England: Ashgate.

Hendy, K. C., Beevis, D., Lichacz, F., and Edwards, J. L. (2002). Analyzing the cognitive system from a perceptual control theory point of view. Defence and Civil Institute of Environmental Medicine, Scientific Literature, DCIEM-SL-2001-143.

Hoffman, R. R., and Militello, L. G. (2009). Perspectives on cognitive task analysis: Historical origins and modern communities of practice. Hove, East Sussex: Psychology Press.

Hou, M. (2015). Report on the development of testbed for integrated GCS experimentation and rehearsal (TIGER). Defence Research and Development Canada, Scientific Letter, DRDC-RDDC-2015-L282.

Hou, M., Banbury, S., and Burns, C. (2014). Intelligent adaptive systems: An interaction-centered design perspective. Boca Raton, FL: CRC Press.

Hou, M., Kobierski, R. D., and Brown, M. (2007). Intelligent adaptive interfaces for the control of multiple UAVs. *Journal of Cognitive Engineering and Decision Making*, 1, pp. 327–362.

Kobierski, R. D. (2013a). UAV operations mission analysis and composite scenario. Defence R&D Canada – Toronto, Contract Report, DRDC Toronto CR-2013-116.

Kobierski, R. D. (2013b). UAS operator target audience description report. Defence R&D Canada – Toronto, Contract Report, DRDC Toronto CR-2013-124.

Kobierski, R. D. (2013c). UAS Preliminary Human Engineering System Analysis Report. Defence R&D Canada – Toronto, Contract Report, DRDC Toronto CR-2013-129.

Lee, J.D., Kirlik, A., and Dainoff, M.J. (Eds.). (2013). The Oxford handbook of cognitive engineering. Oxford, UK: Oxford University Press.

Linegang, M. P., Stoner, H. A., Patterson, M. J., Seppelt, B. D., Hoffman, J. D., Crittendon, Z. B., and Lee, J. D. (2006). Human-automation collaboration in dynamic mission planning: A challenge requiring an ecological approach. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, pp. 2482–2486. San Francisco, CA: Human Factors and Ergonomics Society.

McCarley, J. S., and Wickens, C. D. (2005). Human factors implications of UAVs in the national airspace (Report No. AHFD-05-05/FAA-05-01). Savoy, IL: University of Illinois at Urbana-Champaign, Aviation Human factors Division.

Nehme, C. E., Scott, S. D., Cummings, M. L., and Furusho, C. Y. (2006). Generating requirements for futuristic heterogenous unmanned systems. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meetin*g, pp. 235–239. Los Angeles, CA: SAGE Publications.

Nisser, T., and Westin, C. (2006). Human factors challenges in unmanned aerial vehicles (UAVs): A literature review (Report No. TFHS 05:1). Lund, Sweden: Lund University School of Aviation.

Powers, W. T. (1973). Behavior: The control of perception. New York, NY: Aldine de Gruyter.

Proulx, R., Banbury, S., and Pronovost, S. (2015). TA5: Development of a road-map for human-technology interaction research. Defence Research and Development Canada, Contract Report, DRDC-RDDC-2015-C141.

Rasmussen, J. (1974). The human data processor as a system component: Bits and pieces of a model (Report No. Risø -M-1722). Roskilde, Denmark: Danish Atomic Energy Commission.

Rasmussen, J. (1998). Ecological interface design for complex systems: An example: SEAD- UAV systems. (Report No. AFRL-HE-WP-TR-1999-0011). Air Force Research Laboratory, Human Effectiveness Directorate Crew System Interface Division, Wright-Patterson, OH.

Salmon, P., Stanton, N., Walker, G., and Green, D. (2006). Situation awareness measurement: A review of applicability for C4i environments. *Applied Ergonomics*, 37, pp. 225–238.

Schraagen, J. M., Chipman, S. F., and Shalin, V. L. (Eds.). (2000). Cognitive task analysis. Mahwah, NJ: Erlbaum.

Scott, S. D., Sasangohar, F., and Cummings, M. L. (2009). Investigating supervisory-level activity awareness displays for command and control operations. In *Proceedings of Human Systems Integration Symposium*, pp. 1–12.

US Army. (2012). ADRP 3.0.:Unified Land Operations. Washington, DC: Author., https://www.army.mil/e2/rv5_downloads/info/references/ADP_3-0_ULO_Oct_2011_APD.pdf (Accessed September 11, 2017)

US Department of Defense. (2011). Human engineering requirements for military systems, equipment, and facilities (MIL-STD-46855A). Washington, DC: Author.

Wellens, A. R. (1993). Group situation awareness and distributed decision making: From military to civilian applications. Individual and group decision making: Current issues*,* pp. 267–291. Hillsdale, NJ: Lawrence Erlbaum Associates.

# Annex A Results of the hybrid cognitive task analysis for situation awareness requirements, critical decisions, and cognitive risks

The following table (Banbury, Baker, Tremblay, and Proulx, 2014, pp. 194–196) details the results of the hybrid CTA for situation awareness requirements, critical decisions, and cognitive risks. The table comprises the following data fields (Banbury, Baker, Tremblay, and Proulx, 2014, pp. 129–130):

1. Unit of Analysis. The classification of each entry of the analysis in terms of Function, Goal or Decision. For ease of reading, decisions have been capitalized.
2. Role. The allocation of each decision to one (or more) of the following UAS crew roles:
    a. Air Vehicle Operator (AVO);
    b. Payload Operator (PO);
    c. Image Analyst responsible for viewing current sensor imagery (IMA-A);
    d. Image Analyst responsible for creating and imagery-related intelligence reports (IMA-R);
    e. Electronic Warfare Analyst responsible for monitoring current SIGINT emissions (EW-A);
    f. Electronic Warfare Analyst responsible for creating SIGINT imagery-related intelligence reports (EW-R); and
    g. Linguist responsible for translating SIGINT transmissions for the Electronic Warfare Analysts (EW-L).
3. SA Requirements. The identification of the SA requirements related to each decision. Each SA requirement was also classified as follows:
    a. Mission, Enemy, Terrain, Time, Troops or Civilians (METT-TC); and
    b. Level 1 SA Perception (L1), Level 2 SA Comprehension (L2), or Level 3 SA Projection (L3).
4. Critical Decision. The classification of the decision as *critical* if one of more of the following criteria was considered as an important concern:
    a. Safety;
    b. Mission completion or effectiveness;
    c. Cost;
    d. Efficiency; and
    e. System reliability.

5. Cognitive Risk. The identification of the cognitive risks associated with the decision. Specifically:

    a. Auditory distraction. The adverse effects of irrelevant background sounds on cognitive processing:

        - Complexity. The demands placed on cognitive processing due to the complexity of the tasks undertaken;
        - Decision making biases. Errors in decision making caused by innate human biases and fallibilities;
        - High risk and broad consequences. The psychological stress experienced by humans working in safety-critical and time pressured environments;
        - Inattentional blindness. The inability to perceptually attend to an unexpected change in the environment;
        - Information overload. The increase in cognitive demand and reduction performance due to the effort of finding, interpreting, fusing, and acting on overwhelming amounts of information in order to successfully accomplish tasks;
        - Multi-tasking. The demands associated with performing and focusing cognitive resources on multiple tasks concurrently;
        - Situation awareness. The acquisition and maintenance of adequate levels of SA of the mission environment to support decision making and performance;
        - Skills and knowledge. The level of expert knowledge and skills competency required to successfully operate UASs;
        - Teamwork. The cognitive demands placed on individual operators when functioning within a team;
        - Temporal awareness. The mental representation and understanding of the temporal dimension;
        - Time pressure. The psychological stress resulting from having to get things done in less time than is required or desired;
        - Trust. The level of faith or confidence in the automated systems with less than perfect reliability;
        - Tunnel vision. Characterized by the focusing of attention onto a non-priority visual source of information at the expense of missing priority information in the situation;
        - Uncertainty. The additional demands on cognitive processing when making decisions using information that may be incomplete, imprecise, ambiguous, not current, and of unknown accuracy and reliability;
        - Vigilance. The ability to maintain attention and alertness over prolonged periods of time without increases in error rate or slower reaction times; and
        - Workload. The portion of information processing capacity or resources that is actually required to cope with system demands.

***Table A.1:*** *Results of the hybrid CTA for situation awareness requirements, critical decisions, and cognitive risks (Banbury, Baker, Tremblay, and Proulx, 2014, pp. 194–196).*

| No. | Task | Unit of Analysis | Role | SA Requirements | Critical Decision | Cognitive Risk |
|---|---|---|---|---|---|---|
| 5.1.1 | Ensure UAS is optimized for searching for contacts | Goal | | | | |
| 5.1.1.1 | ARE THE UAS FLIGHT PARAMETERS CONFIGURED CORRECTLY FOR CONTACT SEARCH? | Decision | AVO | Enemy force location (Enemy/L1), Predicted movement of enemy force (Enemy/L3), Terrain type (Terrain/L1), Terrain conditions (Terrain/L1), Vegetation type (Terrain/L1), Current temperature (Terrain/L1), Current precipitation level (Terrain/L1), Current wind conditions (Terrain/L1), Current visibility conditions (Terrain/L1), Predicted impact of future weather on UAS imagery collection (Terrain/L3), UAS location (Troops/L1), UAS EO coverage range (Troops/L1), UAS IR coverage range (Troops/L1), Contact acquired by UAS system (Troops/L1), UAS EO imagery (Troops/L1), UAS IR imagery (Troops/L1), UAS flight systems status (Troops/L2), UAS sensor systems status (Troops/L2), UAS EO imagery exploitation capabilities (Troops/L2), UAS IR imagery exploitation capabilities (Troops/L2), Future likely UAS track (Troops/L3), UAS EW coverage range (Troops/L1), UAS EW/SIGINT data (Troops/L1). | Mission completion or effectiveness, Efficiency. | Situation Awareness, Skills and knowledge, Temporal awareness, Uncertainty. |

| No. | Task | Unit of Analysis | Role | SA Requirements | Critical Decision | Cognitive Risk |
|---|---|---|---|---|---|---|
| 5.1.1.2 | IS THE UAS ROUTE CONFIGURED CORRECTLY FOR CONTACT SEARCH? | Decision | AVO | Enemy force location (Enemy/L1), Predicted movement of enemy force (Enemy/L3), Current temperature (Terrain/L1), Current precipitation level (Terrain/L1), Current wind conditions (Terrain/L1), Current visibility conditions (Terrain/L1), Impact of current weather on UAS imagery collection (Terrain/L2), Predicted impact of future weather on UAS imagery collection (Terrain/L3), UAS EO coverage range (Troops/L1), UAS IR coverage range (Troops/L1), UAS EO imagery (Troops/L1), UAS IR imagery (Troops/L1), UAS flight systems status (Troops/L2), UAS sensor systems status (Troops/L2), UAS EO imagery exploitation capabilities (Troops/L2), UAS IR imagery exploitation capabilities (Troops/L2), Future likely UAS track (Troops/L3), UAS EW coverage range (Troops/L1), UAS EW/SIGINT data (Troops/L1). | Mission completion or effectiveness, Efficiency. | Situation Awareness, Skills and knowledge, Uncertainty. |

| No. | Task | Unit of Analysis | Role | SA Requirements | Critical Decision | Cognitive Risk |
|---|---|---|---|---|---|---|
| 5.1.1.3 | ARE THE EO/IR SENSORS CONFIGURED CORRECTLY FOR CONTACT SEARCH? | Decision | PO, IMA-A | Enemy force location (Enemy/L1), Predicted movement of enemy force (Enemy/L3), Terrain type (Terrain/L1), Terrain conditions (Terrain/L1), Current visibility conditions (Terrain/L1), Impact of current weather on UAS imagery collection (Terrain/L2), Rate of movement of enemy forces (Time/L1), UAS EO coverage range (Troops/L1), UAS IR coverage range (Troops/L1), UAS EO imagery (Troops/L1), UAS IR imagery (Troops/L1), UAS sensor systems status (Troops/L2), UAS EO imagery exploitation capabilities (Troops/L2), UAS IR imagery exploitation capabilities (Troops/L2), Predicted UAS sensor systems status (Troops/L3). | Mission completion or effectiveness, Efficiency. | Situation Awareness, Skills and knowledge. |
| 5.1.1.4 | ARE THE EW/SIGINT SENSORS CONFIGURED CORRECTLY FOR CONTACT SEARCH? | Decision | INTA-A | Enemy force location (Enemy/L1), Enemy force composition (Enemy/L1), Predicted movement of enemy force (Enemy/L3), UAS sensor systems status (Troops/L2), Future likely UAS track (Troops/L3), Predicted UAS sensor systems status (Troops/L3), UAS EW coverage range (Troops/L1), UAS EW/SIGINT data (Troops/L1), UAS EW/SIGINT data exploitation capabilities. | Mission completion or effectiveness, Efficiency. | Situation Awareness, Skills and knowledge. |
| 5.1.1.5 | IS THE COMMUNICATIONS NETWORK CONFIGURED CORRECTLY FOR CONTACT SEARCH? | Decision | AVO | Communication procedures (Mission/L1), UAS communication systems status (Troops/L2), Predicted UAS communication system status (Troops/L3). | Mission completion or effectiveness. | Situation Awareness, Skills and knowledge. |

# Annex B Task authorizations in support of the Human-Technology Interaction project

The overall objective of the DRDC – Toronto Research Centre Human-Technology Interaction (HTI) project is to conduct research on design concepts, approaches and best practices in HTI to support the development and evaluation of emerging Human-Machine System (HMS) concepts for robotic systems within the CAF. The 11 task authorizations, and their respective work items, are summarized as follows (excerpted from Banbury, Pronovost, Pelletier, and Gagnon, 2017, pp. 17–20):

**Task 1: Unmanned aircraft system operator information flow and cognitive task analyses (Banbury, Baker, Tremblay, and Proulx, 2014)**

1.1 *Identification of a Suitable UAS GCS design framework*. A suitable GCS design framework was identified to support future RCAF UAS operational requirements. The analysis reviewed what frameworks are applicable to the current UAS GCS design given the constraints of the project scope, timeline, and available resources. Different front-end and/or back-end analytical methods and design frameworks were compared to determine suitable approaches for the current UAS GCS design.

1.2 *Cognitive Task Analysis*. The CTA activity with suitable Subject Matter Experts (SMEs) derived information requirements and critical decisions for a UAS crew, including both UAS operators and intelligence analysts. Critical decisions were analyzed in terms of the information required to make them. The information was categorized in terms of source (e.g., the threat, system status information, information from other units, outside world situation, etc.) and time constraints on the collection, interpretation and actions required. Decisions were then analyzed for potential for assistance through the recall of stored information or rules, manipulation or analysis, or the application of more advanced techniques of decision aiding.

1.3 *Human-Machine Interface (HMI) Information Requirements*. The identification of HMI requirements drew upon the CTA conducted in work item 1.2 which, for each task studied, listed the information required to undertake the task. Information requirements were grouped in accordance with UAS modes and sub-modes, and states and sub-states. Information requirements included critical communication pathways to describe the HMI "dialogue" between the operators and the system. Persistent information elements were identified along with the portion of the mission for which these elements must remain displayed. The analysis identified the necessary prominence of the information, and the importance of presenting the information in proximity to other related information or the portion of the display that will demand the operator's attention during the conduct of a task.

1.4 *Human-Machine Interface Identification*. Based on the results of work item 1.3, human engineering principles and criteria (including Industry Best Practices with respect to workstation design and office ergonomics) were applied along with all other design requirements to identify and, in a conceptual fashion, to select the particular equipment to be operated or controlled by UAS crew members. The key HMI elements were identified based on the function allocation, task requirements, crew interaction, and SME involvement.

**Task 2: Ground control station design concepts and human factors engineering test plan (Banbury, Pelletier, Baker, Tremblay, and Proulx, 2014)**

2.1 *Development and Evaluation of GCS Design Concepts*. Based on the evolving HMI requirements from work item 1.3, GCS design concepts were developed and evaluated within the context of future RCAF UAS CONOPS. The design concepts included Graphical User Interface (GUI), workstation, and workspace concepts, and were driven by both existing design standards and the analysis of HMI requirements from work item 1.3.

2.2 *Identification of Operator Measures of Performance (MoPs) and HFE Test Plan*. Based on the evolving analysis from work item 1.2, this task identified MoPs to support the evaluation of operator performance during future experimental studies.

**Task 3: Ground control station training needs analysis and performance modeling (Banbury, Forbes, Pronovost, and Tremblay, and Proulx, 2014)**

3.1 *High-Level Training Needs Analysis (TNA)*. Based on the evolving CTA undertaken in work item 1.2, a high-level TNA was conducted to identify the knowledge, skills, and aptitudes required to operate the UAS GCS (including both psychomotor and cognitive skills).

3.2 *Identification of GCS HMI Requirements to Support Operator Training*. Based on the high-level TNA of operator tasks, the training-related requirements for the GCS HMI were developed. Taken together with the results of work item 2.1, the objective of this work was to produce detailed guidance for the HMI design of the GCS.

3.3 *Scope Implementation of Intelligent Tutoring System (ITS) Technologies*. The task reviewed ITS technologies in terms of agent-based design frameworks, operator state monitoring approaches, and previous ITS implementations to identify the means by which ITS technologies can be implemented within the GCS to support both single operator (e.g., other roles performed by the ITS) and team training requirements (as identified by the TNA).

3.4 *Task Flow Refinement and Initial Integrated Performance Modeling Environment (IPME)*. The task flow analysis conducted in work item 1.2 was further refined to support the detailed modeling of operator tasks and information flow (sequencing and timing) across the UAS crew to support the development of an initial IPME task network model. In addition, work was undertaken to scope how this model can be implemented with an IAS to provide real-time adaptation capability based on operator functional state monitoring.

**Task 4: Human factors support to unmanned aircraft system ground control station experimental trial at Air Force Research Laboratory (Banbury, Tremblay, and Gagnon, 2014)**

4.1 *Develop Experimental Protocol*. This task developed an experimental protocol to evaluate operator performance and functional requirements within the current UAS GCS platform developed by AFRL. This work included an initial meeting with SMEs to discuss the trial requirements and objectives.

4.2 *Data Analysis and Reporting*. This task conducted data collation and analysis activities after the experimental trial and report the results.

**Task 5: Development of a road-map for human-technology interaction research (Proulx, Banbury, and Pronovost, 2015)**

5.1 *Research and Development Road-Map*. This work sequenced and integrated the first eight HTI tasks into a research and development road-map to guide the second and third years of the HTI project (and beyond). This road-map was based on, in part, the IAS development framework described in work item 1.1.

**Task 6: Development of an anticipatory competency analysis for JUSTAS (Banbury, Pelletier, Baker, Tremblay, and Proulx, 2015)**

6.1 *Refine List of Competencies for UAS Crew*. This work developed a list of competencies required of the GCS crew for the UAS system derived from the Training Needs Analysis conducted under work item 3.1.

6.2 *Identify training strategies to develop UAS crew competencies*. This work identified suitable training strategies based on the competencies identified in work item 6.1.

**Task 7: Unmanned aircraft system operator task analysis refinement and performance modeling (Banbury, Baker, Pronovost, and Proulx, 2015)**

7.1 *Conduct Error Analysis*. This work conducted an Error Analysis using the Systematic Human Error Reduction and Prediction Approach (SHERPA) methodology to support future tasks conducted within the HTI project, as well as the identification of UAS GCS requirements for JUSTAS project.

7.2 *Conduct CTA Refinement and IPME Modeling.* This work continued the IPME modeling efforts started in work item 3.4 using information collected in work items 2.1 and 3.1. This information included the communication flows between UAS crew members (and automated systems), ratings of workload, and the specific operator competencies required to conduct each crew role.

**Task 8: Unmanned aircraft system ground control station human machine interface and workspace refinement, and human factors engineering trial support (Banbury, Pelletier, and Baker, 2015)**

8.1 *Development and Execution of HFE Trial at AFRL.* This work produced a UAS GCS experimental evaluation protocol and reported on the analysis of collected data during an experimental trial conducted using the TIGER platform at AFRL.

8.2 *Refine and Validate GCS HMI and Workspace Designs*. This work refined and validated the HMI GCS and workspace design concepts developed under work item 2.1 based on, in part, the findings from the findings and recommendations from task 8.1.

**Task 9: Task network modeling to support intelligent adaptive system integration within UAS ground control station (Banbury, and Pronovost, 2016)**

9.1 *Scope IAS Functionality and Capability.* This work scoped the requirements for the 'Authority Pathway' Intelligent Adaptive System (IAS) concept through the identification of UAS operator task requirements, triggering conditions, and the potential functionality and capability of IAS technologies to provide operator support.

9.2 *Conduct IPME Modeling on the Authority Pathway Concept*. This work conducted task network modeling activities on the Authority Pathway concept using IPME. The IPME task models developed in work item 7.2 were partially re-used for this work. This work also developed, and partially executed, a test and evaluation plan to validate the Authority Pathway IPME model through a series of simulation and human-in-the-loop studies.

**Task 10: Human factors support to evaluation of ground control station workspace options (Banbury, Pelletier, and Gagnon, 2016)**

10.1 *Support Human Factors Trial at DRDC Toronto.* This work provided support to the preparations for an evaluation of GCS workspace options identified in work item 8.2 which was executed under Task 11. This work developed a suitable UAS crew concept to promote teamwork within the GCS workspace; developed participant training materials and evaluation criteria; and developed an experimental protocol including evaluation scenarios and participant measures of performance.

10.2 *Develop and Refine GCS GUI Concepts for the Authority Pathway and Shared Crew Displays*. This work refined and validated the Authority Pathway design concepts developed under work items 8.2 and the operator support requirements identified in work item 9.1. In addition, GUI design concepts for large shared crew displays were also developed.

**Task 11: Human factors support to evaluation of ground control station workspace options (Part II; Banbury, Pronovost, Pelletier, and Gagnon, 2017)**

11.1 *Support Human Factors Trial at DRDC Toronto.* This work supported the evaluation and analysis of GCS workspace options at DRDC Toronto based on the technical approach identified by work item 10.1.

11.2 *Refine IPME Model*. This work refined the task network developed by work item 9.2 based on the experimental findings from work item 11.1.

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| AVO | Air Vehicle Operator |
| C2 | Command and Control |
| CAF | Canadian Armed Forces |
| CONOPs | Concept of Operations |
| CTA | Cognitive Task Analysis |
| DRDC | Defence Research and Development Canada |
| EW | Electronic Warfare |
| EWA | Electronic Warfare Analyst |
| GCS | Ground Control Station |
| GDTA | Goal-Directed Task Analysis |
| GUI | Graphical User Interface |
| HGA | Hierarchical Goal Analysis |
| HMI | Human-Machine Interface |
| HMS | Human-Machine System |
| HTI | Human-Technology Interaction |
| IAS | Intelligent Adaptive System |
| IMA | Image Analyst |
| IMPE | Initial Integrated Performance Modeling Environment |
| ISTAR | Intelligence, Surveillance, Target Acquisition, and Reconnaissance |
| ITS | Intelligent Tutoring System |
| JUSTAS | Joint Unmanned Surveillance and Target Acquisition System |
| LPT | Layered Protocol Theory |
| LR | Launch and Recovery |
| MALE | Medium-Altitude, Long-Endurance |
| METT-TC | Mission, Enemy, Terrain, Time, Troops and Civilians |
| MFTA | Mission, Function, and Task Analysis |
| MoPs | Measures of Performance |
| PCT | Perceptual Control Theory |
| PMO | Project Management Office |
| PO | Payload Operator |
| RCAF | Royal Canadian Air Force |

| | |
|---|---|
| RPAS | Remotely Piloted Aircraft System |
| SA | Situation Awareness |
| SAR | Synthetic Aperture Radar |
| SAOD | Situation Awareness Oriented Design |
| SHERPA | Systematic Human Error Reduction and Prediction Approach |
| SIGINT | Signals Intelligence |
| SOI | Statement of Operating Intent |
| SME | Subject Matter Expert |
| TAA | Technical Airworthiness Authority |
| TIGER | Testbed for Integrated Ground Control Station Experimentation and Rehearsal |
| TNA | Training Needs Analysis |
| UAS | Unmanned Aircraft System |
| UAV | Unmanned Aircraft Vehicle |

**DOCUMENT CONTROL DATA**

*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

| | |
|---|---|
| 1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.)<br><br>DRDC – Toronto Research Centre<br>Defence Research and Development Canada<br>1133 Sheppard Avenue West<br>Toronto, Ontario M3K 2C9<br>Canada | 2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.)<br><br>CAN UNCLASSIFIED<br><br>2b. CONTROLLED GOODS<br><br>NON-CONTROLLED GOODS<br>DMC A |

3. TITLE (The document title and sub-title as indicated on the title page.)

Cognitive task analysis for an unmanned aircraft system

4. AUTHORS (Last name, followed by initials – ranks, titles, etc., not to be used)

Arrabito, G. R.; Hou, M.; Banbury, S.

| 5. DATE OF PUBLICATION (Month and year of publication of document.) | 6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.) | 6b. NO. OF REFS (Total references cited.) |
|---|---|---|
| May 2019 | 45 | 60 |

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

Reference Document

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

DRDC – Toronto Research Centre
Defence Research and Development Canada
1133 Sheppard Avenue West
Toronto, Ontario M3K 2C9
Canada

| 9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) | 9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.) |
|---|---|
| 03cb - Human Cognition | |

| 10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) | 10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.) |
|---|---|
| DRDC-RDDC-2019-D041 | |

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

Cognitive task Analysis; Unmanned aircraft system

13. ABSTRACT (When available in the document, the French version of the abstract must be included here.)

The remote operation of an unmanned aircraft system (UAS) usually involves coordination between operators of the system in the ground control station (GCS) and intelligence analysts who are in different geographical locations. The physical separation of these two teams can negatively influence collaboration and timely decision-making during time-sensitive operations. The integration of the UAS operators and the intelligence operators in the same location is expected to improve overall collaboration and decision making. The interface design process to support an integrated UAS operation starts by conducting a Cognitive Task Analysis (CTA) to reveal the cognitive processes that occur in the end users of the technology. This report carried out a CTA with suitable subject matter experts in the Canadian Armed Forces to inform the identification of human machine interface requirements for a UAS GCS. A hybrid analysis technique was employed: mission function task analysis, goal-directed task analysis, and cognitive task analysis. The analysis focused on the critical situation awareness elements that are required by operators to make effective decisions within complex, time critical UAS missions.

L’exploitation à distance d’un système d’aéronef sans pilote (UAS) nécessite habituellement la coordination entre les opérateurs du système au poste de contrôle au sol (PCS) et les analystes du renseignement à différents emplacements géographiques. La séparation physique entre ces deux équipes peut avoir une incidence négative sur la collaboration et la prise de décision en temps opportun lors d’opérations urgentes. Le regroupement au même endroit des opérateurs d’UAS et du renseignement devrait permettre d’améliorer globalement la collaboration et la prise de décision. Le processus de conception de l’interface à l’appui d’une opération d’UAS intégrée implique d’abord une analyse cognitive des tâches (ACT) pour déterminer les processus cognitifs chez les utilisateurs finaux de la technologie. Dans le cadre du présent rapport, des experts en la matière au sein des Forces armées canadiennes ont effectué une ACT afin de définir les exigences d’interface homme-machine pour le PCS d’un UAS. Une technique d’analyse hybride a été utilisée : analyse de missions, de fonctions et de tâches (MFTA); analyse des tâches guidée par les buts (GDTA). Cette analyse portait essentiellement sur les éléments de connaissance de la situation critique dont les opérateurs ont besoin pour prendre des décisions efficaces au cours de missions d’UAS complexes et urgentes.