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Integration of Functions within STUAS Operator Crew on board Royal Netherlands Navy Ships

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Abstract— **Many reasons exist for the military to favor unmanned systems and future missions are envisioned that require longer, more diverse and more frequent deployment of UAVs with increased mission precision. This will also result in a much higher demand on operator crews working with UAVs. With the current pressure on operational budgets, a more effective use of automation is needed in order to answer this demand. This frees operator capacity and enables integration of operator crew functions. This paper describes a case study that was performed to evaluate function integration within a Small Tactical Unmanned Aerial System (STUAS) operator crew on board a Royal Netherlands Navy ship during the flight phase, with the goal to extend the sensory capabilities of the ship: the Air Vehicle Operator (AVO) and the Payload Operator (PO) tasks allocated to one operator. Also a combined AVO/PO-interface was provided to this one operator and was evaluated. Results show that, for simulated maritime scenario as used in this evaluation study, integration of STUAS functions and interfaces can still lead to effective operations. Types of missions and flight phase operator tasks not addressed in this study remain subject of future study. This study should therefore be regarded as a first step of the full analysis of the possibilities for integration of STUAS functions and interfaces together with the enabling automation and support.**

I. INTRODUCTION

In the last decade, there has been a strong growth in the development and employment of Unmanned Aerial Vehicles (UAVs). Notwithstanding budget cuts for the Ministry of Defense, there is an increase in budget available for the procurement of UAVs in the Netherlands [1], resulting from a vision stating "unmanned if we can, manned if we must". Many reasons exist that favor unmanned systems, in particular for the military, where integration of unmanned systems is expected to result in less risks of losing human life, the ability to reach sites difficult to access, and the ability to reach higher mission precision due to for instance the wide variety of sensor payloads [2], [3], [4]. As an inevitable result, operator-automation integration and interfaces [5], [6], [7], [8] and operator crew configuration [9], [10], [11] are important topics of research.

The ScanEagle Small Tactical Unmanned Aerial System (STUAS) recently acquired by the Joint Intelligence Surveillance Target Acquisition and Reconnaissance Command (JISTARC) of the Royal Netherlands Army (RNLA) introduces new opportunities and possibilities. Striving for an optimal mission effectiveness, this requires careful integration of this newly acquired capability in the military's existing operations. In order to successfully exploit the ScanEagle's capabilities, many factors have to be considered, such as doctrine, organization, command structures and information management.

Currently, the primary task of JISTARC is to provide other military units with intelligence for strategic purposes and mission planning. In this type of operations (from now on called "future-ops") the intelligence collection task typically takes a couple of days or weeks. JISTARC's main operational area is above land and their materials, manning, procedures and line of command are also tailored to operations above land. However, JISTARC can also be attached to a maritime hosting unit, for example a Royal Netherlands Navy (RNLN) ship participating in counter piracy operations. In such a case the STUAS can be tasked for "current-ops" by the ship's Commander, for example to support force protection operations. Recently the STUAS was deployed for the second time by JISTARC on a naval mission. A crew of twelve persons of JISTARC, assisted by instructors, was on board the Landing Platform Dock "Zr. Ms. Johan de Witt" (LPD2) of the RNLN to prepare their mission to Somalia and to licence part of the JISTARC crew. First experiences made clear that this type of operations has different demands and consequences than for future-ops on land, and therefore would require JISTARC to expand and increase its capabilities according to these new demands and consequences. This motivates the need for further exploration of the possibilities for STUAS deployment for such new kinds of operations.

One of the prime discussions about consequences concerns manning issues. Improper integration of crew can for instance hinder situation awareness and introduces a lot of communication overhead, possibly reducing mission effectiveness. By carefully integrating tasks, where possible, within the STUAS crew or with the hosting platform crew, mission effectiveness can be maintained or even improved. The biggest benefits of integration of functions within the STUAS operator crew are, when keeping the total amount of personnel equal, that more personnel is available for performing the mission, enabling even round-the-clock operations. Moreover, difficulties in the regulation of conversations, problems with not sufficiently sharing situation awareness, and other process losses from working with larger crews may be reduced, making the crew more efficient and perhaps even more effective.

In this paper we present new concepts focusing on the integration of a STUAS Integrator operator crew on board of RNLN ships. Further we present the results of a case study

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testing our concept of integrating two STUAS functions (i.e., the Air Vehicle Operator (AVO) and the Payload Operator (PO)) during the flight phase. Experienced personnel performed a operationally valid current-ops Navy counter-piracy operation in an advanced simulated environment, in close collaboration with a crew in a Navy Command Center with the goal to extend the sensory capabilities of the ship. Two variants of integration of the AVO and PO interface were tested on the crews participating in our studies. After each simulated scenario, feedback from the operators was collected. For this purpose, Concept Development and Experimentation (CD&E) was used, which is a forward-looking process for developing and evaluating new concepts by experiencing them in a simulated setting before committing extensive resources [12]. The results obtained from this CD&E procedure are indicative of the practical feasibility of the concepts tested and are used as a guide to further drive our research efforts.

This paper is composed of the following sections: in Section II the background behind the integration of functions is described. This section also identifies the current knowledge gaps in the unmanned systems literature. In Section III the evaluation experiment is described and its results are described in Section IV. Then, in Section V, the conclusions concerning the envisioned integration of functions within the STUAS crew on board RNLN ships are presented.

II. BACKGROUND

A. Today's Approach

Today's primary task of the STUAS in the RNLA is to provide other military units with intelligence for strategic purposes and mission planning. In this type of operations (i.e., future-ops), results of the mission are documented in a report and transferred to the requesting unit. A future-ops type of operation is directed by the Mission Commander. During future-ops, operator teams consist of four members: an Air Vehicle Operator (AVO), a Payload Operator (PO) and two Image Analysts (IA). The higher ranked IAs are responsible for the result of the mission, and direct the operators where to lead the air vehicle and where to look at with the camera. The AVO is responsible for the flight safety and compliance of the mission with aviation regulations.

In the case of the STUAS being attached to a RNLN ship, the STUAS can be employed for tactical operations in the ship's mission, and operates under direct command of the ship's Commander (i.e, current-ops). Combined with the ship's other sensor data, information from the STUAS enriches the common operational picture.

During current-ops, the line of command is defined as shown in Fig. 1. While the primary task of the STUAS crew is to advise the Command Center Officer (CCO), a liaison officer (LSO) of the STUAS is responsible for the decision whether the STUAS crew can accept the current-ops demand of the CCO. This LSO is located in the Command Center. During the current-ops operation the CCO directly communicates with the IA of the STUAS, who directs the AVO and PO. The AVO is ordered by the Air Controller in

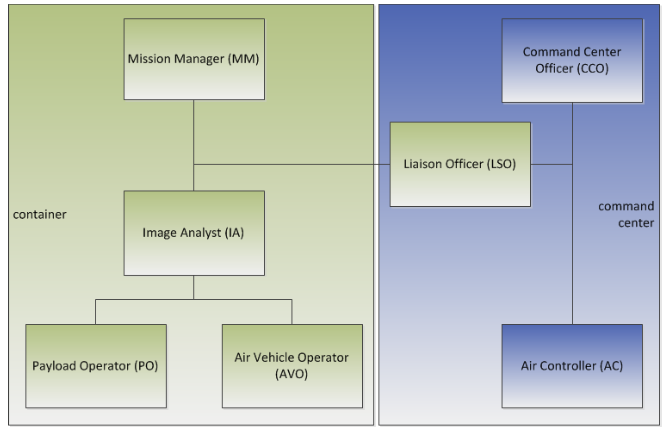


Fig. 1. Today's line of command during current-ops missions.

the Command Center about flight safety issues and aviation regulations. The camera images are also directly visible in the Command Center, which enables the CCO draw conclusions based on the images in consultation with the IA.

B. Tomorrow's Approach

The introduction of the STUAS on board Navy ships requires an increase of crew members. One of the causes of that increase is the extra crew that is necessary for the control of UAVs and the analysis of the camera images. Also, today's STUAS deployment approach is modular, meaning that it has a self-supporting crew. This may cause an overlap of tasks with the crew to which the module is attached, such as the task command, planning and maintenance. As today's approach is tailored to future-ops on land, new manning and interface concepts in tomorrow's approach may lead to the possibility to integrate functions within the STUAS crew so that less people are required to fly a UAV. Of course, function integration must be considered very carefully, as on a Navy ship many different situations may occur, including emergency situations, and function integration must be tailored to all of those, without for instance the risk of excessive work load (including within the STUAS crew) and violation of the related work regulations.

As future missions are expected to demand longer, more diverse and more frequent deployment of UAVs with increased mission precision, this also results in an increased pressure on the STUAS crew. Since function integration frees operator capacity, same sizes of the STUAS crew could result in the ability to execute these longer and more frequent missions. This may even enable round-the-clock operations. Moreover, coordination costs from working with less integrated functions may be reduced, making the crew more efficient and perhaps even more effective [13]. With function integration, communication automatically may become less difficult and communication mishaps may occur less easily. Furthermore, function integration may allow team members to better keep up-to-date with the changes in the situation, and to evaluate and improve task performance more

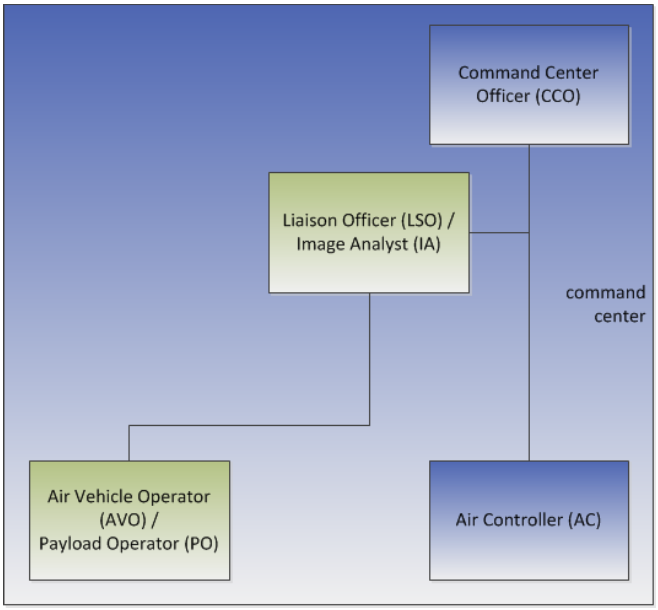


Fig. 2. Tomorrow's line of command during current-ops missions.

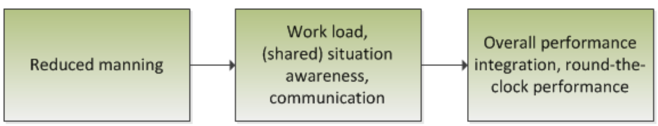


Fig. 3. Consequences of reduced manning concepts.

easily [14].

For current-ops scenarios, the STUAS team should ideally be integrated within the Command Center, with a line of command of only four persons, as shown in Fig. 2. In this figure, the AVO/PO are integrated in one operator. This integration is described in the next paragraph.

C. *Integration of STUAS Operator Functions*

Advances in technology suggest the possibility of reducing the size of the crew required to operate UAVs, such as the STUAS, from as many as four people to two or less. But current crew concepts are often still based on the more complex and demanding concept of their predecessors or other mission types. Advances in technology and features not previously available to crews may justify a new crew concept and even new operating procedures.

Advances in technology, however, may also introduce new cognitive demands such as the need to monitor more UAVs and to operate multiple sensors at the same time (see also [15]). The possible consequences of reduced manning are an increased mental effort, less (shared) situation awareness and communication, which in turn will influence performance (see Fig. 3). The challenge therefore is to find an optimal integration solution for a reduced manning concept, without exceeding the mental capacity of the remaining crew. This eventually has to be assessed over all possible operational concepts and other phases of the mission, of which this study is a first step.

Based on the literature and on interviews with key JISTARC personnel during the deployment of the ScanEagle on board the LPD "Zr. Ms. Johan de Witt" of the RNLN, and with a staff officer of DEC3D Land Warfare Centre the following options for integration of operator functions are possible. The future-ops approach allows for integration of either the AVO/PO or the PO/IA functions. Other combinations for future-ops are either illogical (AVO/IA), or impossible (a single IA). For current-ops, due to the absence of the integration of the IA with the LSO in the Command Center, only the combination AVO/PO is an option. Besides these types of integration, another option for integration could be to assign multiple STUAS platforms to a single person rather than assigning them to different persons. However, since the present operations are mainly executed with a single platform, for this study we chose to exclude this possibility. Hence combining the AVO and PO functions in the STUAS operator crew (i.e., the integrated STUAS operator (ISO)) appears to be most obvious.

D. *Integration of STUAS Operator Interfaces*

The reduction of the size of the STUAS operator crew from two to one, results in the combination of tasks that were previously distributed amongst two operators. In this situation the "cognitive task load" and "situation awareness" of the operator is critical to prevent a decreasing performance. These two concepts are described in the following two paragraphs.

1) Cognitive Task Load: The Cognitive Task Load (CTL) theory distinguishes three load dimensions [16]. The first dimension is the "time occupied". The time occupied is said to be high when the operator has to work with maximum cognitive processing speed to search and compare known visual symbols or patterns, to perform simple (decision-making) tasks, and to manipulate and deal with numbers in a fast and accurate way. The second dimension is the "level of information processing". For dimension the following can be said: 1) information that is processed automatically, results into actions that are hardly cognitively demanding, 2) routine procedures involve rather efficient information processing, and 3) problem solving and action planning for relatively new situations involve a heavy load on the limited capacity of working memory. "Task set switches" is the third load dimension, and addresses the demands of attention shifts or divergences in which different sources of human task knowledge have to be activated. For an overview of these three levels, see Fig. 4. It should be noted that the effects of cognitive task load depend on the duration of the concerning task. In general, the negative effects of under- and overload increase over time.

2) Situation Awareness: Situation Awareness (SA) is the *perception* of environmental elements with respect to time and/or space, the *comprehension* of their meaning, and the *projection* of their status after something has changed [17].

- Perception (level 1). Perception of cues in the environment is fundamental to situation awareness. Humans perceive the environment through one or more of their

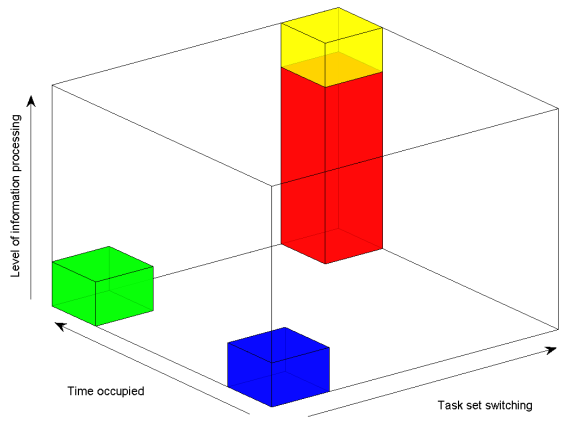


Fig. 4. Cognitive Task Load (CTL) model with four general problem regions [16]: vigilance (blue), underload (green), overload (yellow) and cognitive lock-up (red).

five senses (visual, auditory, tactile, taste or olfactory senses). Without good perception, situation awareness is incomplete and errors will arise.
- Comprehension (level 2). Comprehension of the perceived information is the second level of situation awareness. It encompasses how people combine, interpret, store, retain, and retrieve information, how they integrate different pieces of information, and how they relate the information to their goals.
- Projection (level 3). The ability to project from the current situation into the (near) future allows for timely decision-making.

Building up SA is a crucial part of the tasks allocated to STUAS operators. An example of an experiment related to SA and UAV operators and interfaces is presented in [9], where an integrated display was studied in which the visual elements were integrated for the control of the platform as well as the payload during wilderness search and rescue operations. The interface was compared against a "split-window" interface in which both interfaces were side-by-side. The authors made several conclusions:

1) Providing clues about autonomously detected signs heavily increased performance.
2) The more demanding the navigation task, the less situational awareness was gained.

The challenge is to design an interface that can support one operator to have platform and payload control instead of either platform or payload control, in such a way that the cognitive task load and situation awareness are on an optimal level.

E. Research Objective

We explore possibilities to combine and integrate the basic tasks of the AVO and the PO during flight phase, currently being fulfilled separately by two persons, by allocating these tasks to a single person (i.e., the integrated STUAS operator (ISO)). We expect that with sufficient support from the human-machine interface it will be the case that performance, situation awareness, mental effort, satisfaction and communication of the new and reduced STUAS crew will be adequate and at least at the same level of larger STUAS crew. We will evaluate this by using a single scenario related to current-ops STUAS operations on board RNLN ships with a focus on parts of the basic tasks carried out by current STUAS operators from JISTARC. The research objective is to gain "lessons learned" that can be used for further evaluation with respect to additional flight phase tasks, tasks to be executed before or after the flight phase, and the full spectrum of operations.

III. METHOD

A. Participants

A team of three experienced STUAS operators from JISTARC (took the role of AVO, PO and IA) and a team of four experienced RNLN Command Center operators and officers (took the role of CCO, AC, Assistant CCO (ACCO), Unmanned Surface Vehicle (USV) operator) participated in the CD&E evaluation study. Several roles were taken by experimenters (as opposed to participants): Medium Altitude Long Endurance Unmanned Aerial Vehicle (MALE UAV) operator, the Commander on the bridge and all possible contacts in the outside world to which the participants could communicate.

B. Task and Scenario

The available assets in the scenario were a simulated Offshore Patrol Vessel (OPV), MALE UAV, STUAS and USV. A team of an AVO, PO and IA of a Insitu RQ-21A STUAS Integrator [18] was responsible for protecting Sea Lanes of Communication (SLOC) against pirates attacking merchant vessels in the SLOC. Each of them had a distinct task in the process of identification and classification of pirates. The AVO was responsible for controlling the UAV and compliance to flight regulations. The PO was in control of the sensors such as a gimbal camera, without the task of interpretation of the sensor images. This task was up to the IA, who used the sensor payload to detect and correctly classify and identify contacts.

Besides the STUAS team, a CCO was involved. Together with the ACCO and AC, his task was to command and direct the STUAS team and the USV operator. The USV operator extended the capabilities of the OPV, but was not subject of this study. The MALE UAV provided additional contact information, but executed its tasks autonomously. For this study the focus was on the STUAS team.

The evaluation took place in a laboratory environment where interfaces of the different team members and the SLOC scenario were implemented in the *Advanced Concept Development and Experimentation Environment (ACE)* (see Fig. 5.

The *simulated* Integrator had a 55 kn cruise speed, 15 h endurance, 100 km LOS range, 3000 ft operational altitude was and only equipped with an Electro Optical (EO) camera.

Fig. 5. Advanced Concept Development and Experimentation Environment (ACE). In the back from left to right: the USV operator, ACCO, AC, IA and ISO (knee visible). In the front: the CCO.

The *real* Integrator (as opposed to the simulated one) can be seen in Fig. 6. The Integrator is a small Class 1 UAV used for surveillance, reconnaissance and targeting. It is unarmed and, apart from a relatively small area for aircraft launch and recovery equipment, does not require infrastructure like runways for take-off or landing. It is designed for long endurance at low to medium altitudes. It has a wingspan of $4.8\,\mathrm{m}$, a length of $2.2\,\mathrm{m}$ and an empty structure weight of $34.0\,\mathrm{kg}$. The maximum altitude of the Integrator is $5000\,\mathrm{m}$, its maximum speed is $80\,\mathrm{kn}$ and its maximum flight time is $12\,\mathrm{h}$.

The STUAS team performed a surveillance task in a Gulf of Oman scenario [19]. It was a blue water operation geographically located between Oman and Pakistan (see Fig. 7). The operational area for which the Mission Commander was responsible was $162\,\mathrm{M}$ by $162\,\mathrm{M}$ ($300\,\mathrm{km}$ by $300\,\mathrm{km}$). Ships moving through the Gulf of Oman followed a Traffic Separation Scheme (TSS), which separated inbound from outbound merchant vessels to reduce the risk of collision. The shipping lane was $5.2\,\mathrm{M}$ ($9.6\,\mathrm{km}$) wide, including two traffic lanes, one inbound and one outbound, both $1.7\,\mathrm{M}$ ($3.1\,\mathrm{km}$) wide. The two traffic lanes were separated by a $1.7\,\mathrm{M}$ ($3.1\,\mathrm{km}$) wide separation median. Pirates originated from the south-west. They were loitering near the sea lane inside the fishing area (to the south of the sea lane), but possibly also to the north of the sea lane (between the second fishing area in the north and the sea lane). The hostile units were trying to hide themselves between local traffic vessels. Note that besides the own air assets, the scenario did not contain other air traffic in the operation area. Apart from merchant vessels and pirate boats, also other ships, like

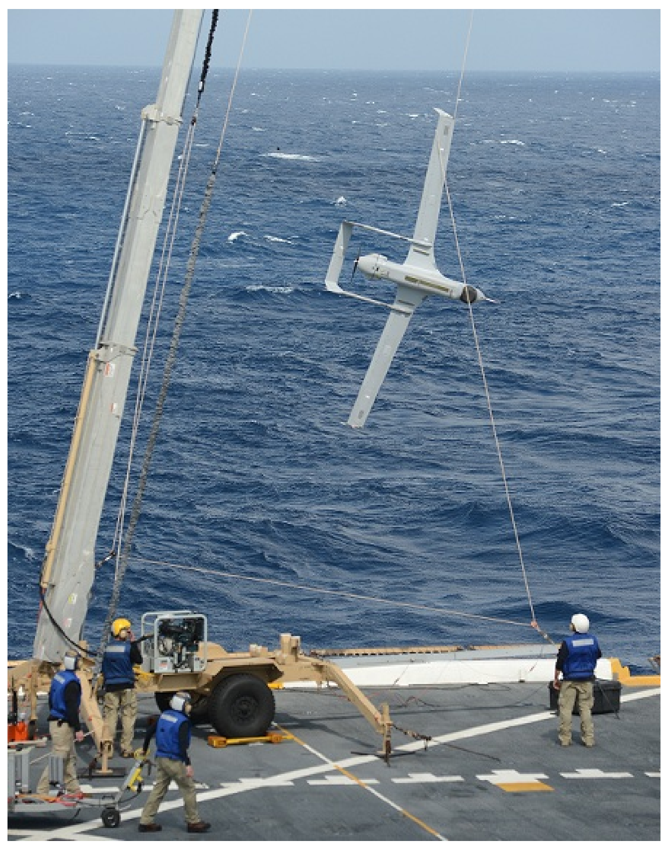


Fig. 6. The U.S. Navy's Insitu RQ-21A STUAS (Integrator) being recovered by Insitu's SkyHook capture rope from the San Antonio class dock landing ship USS Mesa Verde (LPD-19) after one of its first operational flights (U.S. Navy photo [18]).

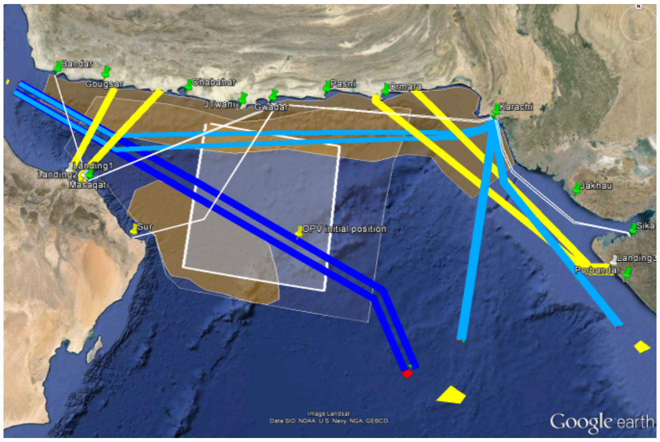


Fig. 7. Operation area (Gulf of Oman). Blue lines are sea lanes, white lines are ferry routes, yellow lines are smuggler routes and brown areas are fishing areas.

fishing boats, sailing boats and speed boats, were using the traffic lane in the Gulf of Oman. Once the STUAS team had detected one of these contacts, it had to correctly identify it as being either neutral or hostile (pirate). In case the contact was identified as pirate, it had to be intercepted by helicopter (NH-90), USV or FRISC, which was not part of the scenario nor task for the STUAS crew or ship's crew.

C. Conditions

The used conditions for the CD&E evaluation study are shown in Table I.

TABLE I
THE THREE CONDITIONS USED IN THE CD&E EVALUATION STUDY.

	Integration Type	
Condition	Functions	Interfaces
1 (baseline)	no	no
2	yes	no
3	yes	yes

1) Condition 1 (baseline): In Fig. 8 a schematic overview of the interfaces used in this study is shown for each condition. In condition 1 (baseline condition) the AVO had two displays: The one on the left, the "System screen" contained:

a) Communication: allowed the operator to talk with the CCO, PO and IA.
b) Small EO Camera: this was a small version of the PO screen.
c) Notes: allowed the operator to send (chat) messages to the CCO, PO and IA. It was not mandatory to use it (could also use the radio (see a)).

The next display, the "Tactical screen" contained:

d) Mission: a tool that allowed the operator to create a mission by adding a route and set the coordinates, altitude and speed.
e) Map: allowed the operator to follow the aircraft and set way points.
f) Subsystem Status: alerted the operator for all aircraft malfunctions.
g) Multiple Tabs:
   1) Engine Status: showed information of the engine: e.g., RPM, temperature oil pressure, etc.
   2) Flight director: showed rotation about both the longitudinal axis to indicate the degree of bank, and about the lateral axis to indicate pitch.
   3) Elevation Profile Mission: showed the elevation of the aircraft during a mission.
   4) Elevation Profile Prediction: showed the predicted elevation profile of the aircraft.

The AVO's interface included a mouse and keyboard for setting or altering way points. The left picture in Fig. 9 shows the interface used for the AVO in ACE.

In condition 1 the PO had just one display: The "Camera screen", which is depicted on the right side of Fig. 8. This screen showed the video images of a rotatable Full Motion Video (FMV) camera mounted on the bottom of the air vehicle. The interface included a mouse, keyboard and joystick to control the sensor. The right picture in Fig. 9 shows the interface used for the PO in ACE.

2) Condition 2: The interface in condition 2 was identical to condition 1. Furthermore, the two operator functions, AVO and PO, were allocated to one operator (i.e., the integrated STUAS operator (ISO)) instead of two, as compared to condition 1. The scenario used was a slightly modified version of the scenario used in condition 1, to prevent entrainment of the crew (which in turn could have caused a misleading bias in the results).

3) Condition 3: Condition 3 was similar to condition 2 with only one alteration: the "Tactical screen" and "Camera screen" was displayed on the same monitor, but only one of them at the time. The ISO could change screens by means of a monitor switch (as indicated by "i" in Fig. 8). Again, the scenario was slightly modified as compared to the scenarios used in conditions 1 and 2, to prevent entrainment of the crew.

D. Measures

1) Situation Awareness: The operators were asked to rate statements about their perceived SA, on a scale from 1 (totally disagree) to 5 (totally agree). These statements referred to levels 1 and 2 of SA [17], which are most important for operator tasks:

1) I knew exactly where to find information on the display.
2) It was easy for me to locate tracks.
3) I had a good understanding of the overall situation.
4) At all times I was aware of the position of the camera.
5) I had a good idea how to position the camera when approaching a track.

2) Subjective Mental Effort: In [20], O'Donnell and Eggemeier define mental effort as the ratio between the task demands and the capacity of the operator working on the

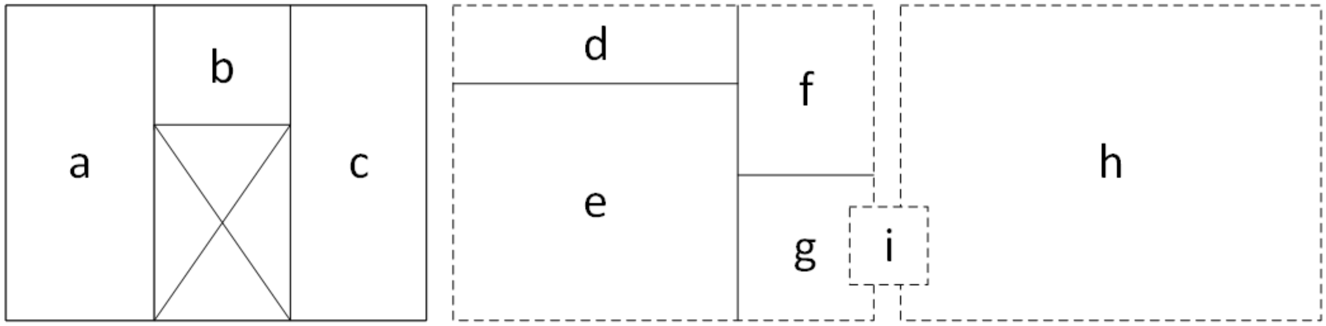
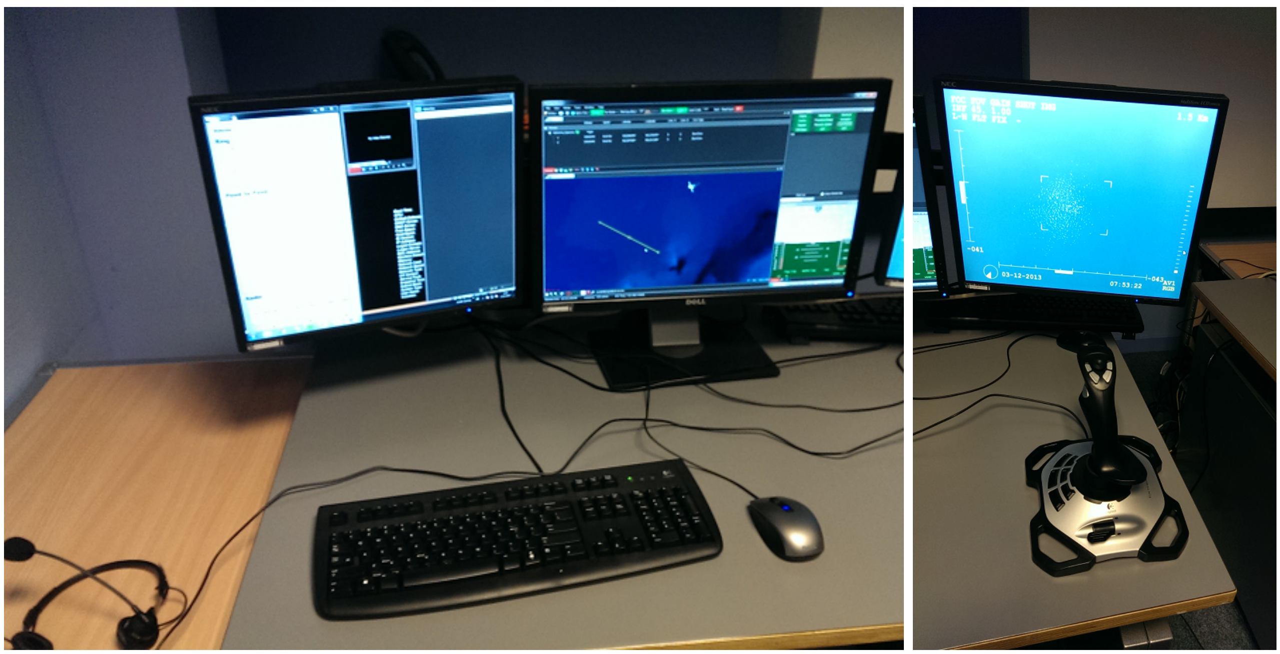


Fig. 8. The positions of the different tools on the interface in conditions 1, 2 and 3 as explained in the text. In condition 1 the AVO had only the "System screen" and "Tactical screen" and the PO had the "Camera screen". In condition 2 all the screens were available for just one operator (i.e., the ISO). In condition 3 a monitor switch (as indicated by a "i") was used to change his second monitor from a "Tactical screen" to a "Camera screen" and vice versa.



(a) (b)

Fig. 9. Actual interface of the AVO (a) and PO (b) in the ACE.

task. Mental effort is high when the difference between task demands and capacity is small. The Rating Scale Mental Effort (RSME) was used to evaluate the subjective mental effort of the STUAS operators and the CCO *during* and *after* each condition (the scores of the CCO are included as an indication of the eventual influence of the conditions on mission effectiveness). The RSME, originally developed by Zijlstra [21], is a one-dimensional scale with ratings between 0 and 150. The scale has nine descriptive indicators along its axis (e.g., 12 corresponds to "not effortful", 58 to "rather effortful", and 113 to "extremely effortful"). It is designed to minimize individual differences. We selected the RSME because it is simple to administer, not intrusive, and at the same time it has proven to be a good indicator of the total mental effort [22], [23].

E. Procedure

The participants arrived at 8 am and left 5 pm (total of 9 h, including 1 h break). First the participants were briefed about the goal of the CD&E evaluation study and the ACE. Each participant got a role (for STUAS: AVO, PO (or ISO) and IA, and for Navy: CCO, ACCO, AC and USV operator) for each condition, depending on their experience with that role. Before a condition stated, it was explained what exactly changed as compared to the previous condition. Each condition took 50 min. During each condition participants were required to indicate their subjective mental effort by drawing a line in a graph. After each condition, participants received the situation awareness and subjective mental effort questionnaires. After filling in the questionnaires, a debriefing was done, where each participant was able to give extensive feedback on the different aspects of the conditions.

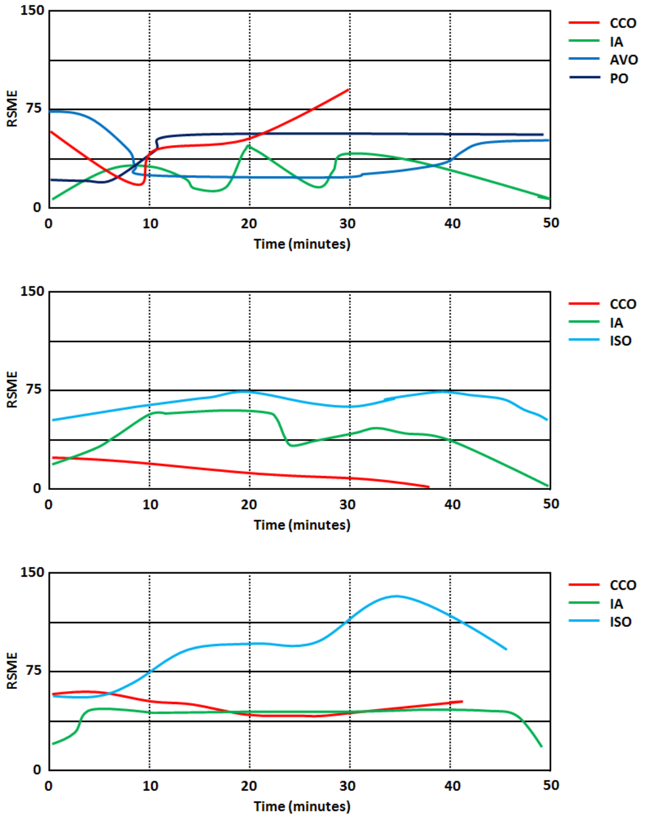


Fig. 10. RSME scores during conditions 1 (top figure: no function and interface integration), condition 2 (middle figure: function integration without interface integration) and condition 3 (bottom figure: both function and interface integration), as a function of scenario time (50 minutes). No excessive peaks in subjective mental effort were reported, where AVO and PO functions where combined without integration of the interfaces (condition 2).

IV. RESULTS

A. Integration of STUAS Operator Functions

No excessive peaks in the RSME were observed *during* the scenarios in conditions 1 and 2, meaning that the subjective mental effort was acceptable for each moment during the run where the STUAS operator functions were integrated, without integration of the interfaces (see middle figure in Fig. 10). The scores of the CCO are included in Fig. 10 as an indication of the eventual influence of the conditions on mission effectiveness.

Also the RSME as indicated by the operators and the CCO *after* the different scenarios was low, meaning that the overall subjective mental effort was acceptable in each condition, including conditions 2 and 3, where the STUAS operator functions were integrated (see Fig. 11).

With respect to communication, it was mentioned that some mishaps occurred as a consequence of different ways of working between armed forces and naval personnel. It was voiced that these difficulties could have arisen due to time constraints at the beginning of the conditions and could have easily been prevented if taken more time beforehand in making clear arrangements on how and when communication

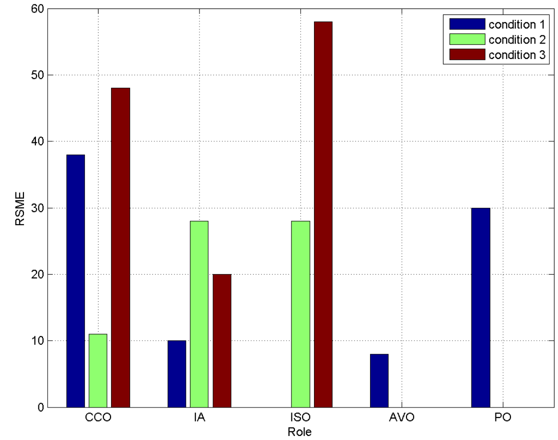


Fig. 11. RSME scores as rated by the operators and the CCO after each condition. The overall subjective mental effort was acceptable in each condition, where AVO and PO functions were combined (conditions 2 and 3). Note that the AVO and PO were only present in condition 1 and the ISO only in conditions 2 and 3.

should take place.

As operators indicated that in real world operations they are used to have more tasks to be carried out during the flight (such as system monitoring and avoidance of air traffic), it was difficult for them to extend their opinion to the full spectrum of operations. However, it is clear from the results that in this particular study the ISO was able to combine the AVO and PO tasks without excessive subjective mental effort.

B. Integration of STUAS Operator Interfaces

The integration of the STUAS operator interfaces was received by the crew with less enthusiasm. As shown in Fig. 11, the support added in condition 3, where the ISO had to switch between the AVO and PO interfaces, substantially increased subjective mental effort for the operator as compared to condition 2 without the switch (although still low). The ISOs indicated that they missed the extra display and that the switch added extra effort in keeping the situation awareness up-to-date. Also the CCO indicated an increased RSME for condition 3 as compared to conditions 1 and 2. Condition 2, however, resulted in less RSME for the CCO as compared to condition 1. This suggests that integration of STUAS operators, not integration of STUAS interfaces, could also eventually result in lower mental effort for the CCO.

In Fig. 12 the results on situation awareness are shown. Answers to questions 2, 4, and 5, show that operators had a better situation awareness in condition 3 (with switch) as compared to conditions 1 and 2. It could be the case that in condition 3 the operator had learned to use the interface more effectively. It could, however, also be the case that the increased mental effort, as can be observed from Fig. 11, resulted in the beneficial additional effect of an improved situation awareness.

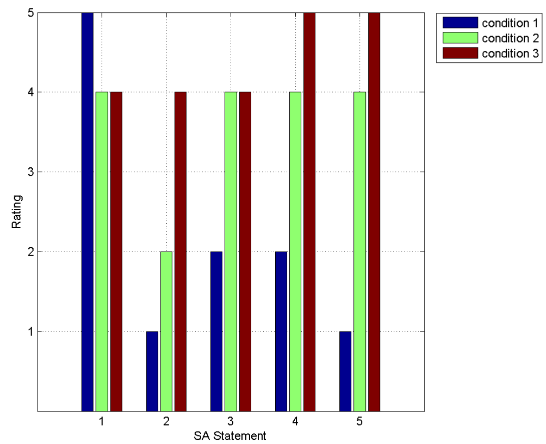


Fig. 12. Answers by operators to the situation awareness questions. Note that for condition 1 the answers of the PO are shown and for conditions 2 and 3 those of the ISO are shown.

V. DISCUSSION AND CONCLUSIONS

As future missions are expected to demand longer, more diverse and more frequent deployment of UAVs with increased mission precision, this also results in an increased pressure on the STUAS crew. This pressure can be lowered by freeing operator capacity by a more effective use of automation enabling integration of operator crew functions and interfaces.

The goal of this research was to explore the possibilities with respect to integration of the STUAS functions and related interfaces, during flight phase, in current-ops missions, on board RNLN ships. As a first step this paper reports an evaluation of the integration of the AVO and PO functions with and without interface integration. From this evaluation we can draw several preliminary conclusions, which are summarized below.

Firstly, for interface integration it was found by crew members that switching between interfaces interfered with mission effectiveness and led to unwanted increases in operator mental effort. In our opinion, interface integration should help STUAS operators in achieving comparable levels of mission effectiveness, while at the same time reducing mental effort (as compared to without interface integration). For the chosen integration, the opposite was observed, however, meaning that it might interfere with mission execution. On the other hand, an improved SA was measured when interface integration was applied. This might suggest that the mentioned increased mental effort had the beneficial additional effect of an improved situation awareness. I.e., the increased mental activity simply was used to increase SA. It remains to be studied whether this was indeed the case or that it was the result of poor interface design without any beneficial effects. Also current regulations might rightly forbid the temporary inhibition of important air vehicle information on the AVO interface, which should also be taken into account when designing future integrated AVO/PO interfaces.

Secondly, for maritime scenarios as used in this CD&E evaluation study, the results showed no consequences of integrating AVO and PO functions into a single operator with respect to the measured subjective mental effort and situation awareness. In this respect, AVO and PO tasks could thus indeed still be executed effectively by one operator, with less communication and experienced communication difficulties. Overall, subjective mental effort remained well below critical borders.

It should be noted that this research is based on a particular case study and that as a result only one crew was involved (as opposed to experimental research done using multiple sessions with many more participants). Although the sample was representative of the population, which is very small, the conclusions therefore should not be considered as firm or well established as it is not certain that the critical causes were identified in the observed outcomes from an experimental point of view. Furthermore, in spite of the used advanced simulation environment (ACE), there were some (inevitable) limitations with respect to its similarity to actual missions. Operators for instance stated that certain factors of influence, such as interruptions by other crew members and other work processes, were not well embedded in the current simulation, therefore resulting in a less rich and demanding experience for crew members. Operators also indicated that the AVO interface had less functions and information than they were used to have during training and missions.

As was stated in the research objective of this paper, the results are to be interpreted as “lessons learned” that can be used for further evaluation (i.e., qualitative research). This further evaluation should focus on additional flight phase tasks, tasks to be executed before or after the flight phase (such as the setup and take-down of the SkyHook recovery system) and more dynamic types of operations (such as those on land) which introduce higher demands for the STUAS crew. Hence, this study should be regarded as a first step of the full analysis of the possibilities for more effective use of STUAS automation, by means of integration of functions and interfaces, with the goal to eventually cope with the future demands of longer, more diverse and more frequent deployment of UAVs with increased mission precision.

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REFERENCES

[1] C. Klapwijk and H. W. Meerveld, "Unmanned aerial vehicles: Het debat over de opkomst van onbemande vliegtuigen," *Militaire Spectator*, no. 11, pp. 484–494, 2012.

[2] L. Campbell, "The debate: Manned vs unmanned," *FrontLine Defence*, vol. 2, pp. 14–15, 2011.

[3] N. J. Cooke and H. K. Pedersen, "Unmanned aerial vehicles," in *Handbook of Aviation Human Factors*, 2nd ed., J. A. Wise, V. D. Hopkin, and D. J. Garland, Eds. Boca Raton, FL: CRC Press, 2009, pp. 18–1–18–8.

[4] L. R. Newcome, *Unmanned Aviation: A Brief History ofUnmanned Aerial Vehicles*. Washington, DC: AIAA, 2004.

[5] J. M. Peschel and R. R. Murphy, "On the human-machine interaction of unmanned aerial system mission specialists," *IEEE Tansactions on Humn-Machine Systems*, vol. 43, no. 1, pp. 53–62, 2013.

[6] M. L. Cummings, S. Bruni, S. Mercier, and P. J. Mitchell, "Automation architecture for single operator-multiple uav command and control," *International Command and Control Journal*, vol. 1, no. 2, pp. 1–24, 2007.

[7] A. P. Tvaryanas, "Human systems integration in remotely piloted aircraft operations," *Aviation, Space, Environmental Medicine*, vol. 77, no. 12, pp. 1278–1282, 2006.

[8] R. M. Taylor, "Human automation integration for supervisory control of UAVs," in *Proceedings of Virtual Media Military Applications Meeting*, 2006, pp. 12–1–12–10.

[9] J. L. Cooper and M. A. Goodrich, "Towards combining uav and sensor operator roles in uav-enabled visual search," in *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction*. New York, NY: ACM, 2008, pp. 351–358.

[10] B. Walters and M. Barnes, "Manpower, skill, and fatigue analysis of future unmanned aerial vehicle (UAV) environments," in *Proceedings of the Human Factors and Ergonomics Society 46th annual meeting*, Baltimore, USA, 2002.

[11] B. Walters and M. J. Barnes, "Modeling the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles (UAVs)," in *Proceedings Winter Simulation Conference*, 2000, pp. 920–924.

[12] The Technical Cooperation Program (TTCP), *Guide for Understanding and Implementing Defense Experimentation (GUIDEx)*, 1st ed. Ottowa, Canada: TTCP JSA AG-12, February 2006.

[13] R. Van der Kleij and J. M. Schraagen, "Enabling team decision making," in *Creating high-tech teams: Practical guidance on work performance and technology*, C. Bowers, E. Salas, and F. Jentsch, Eds. Washington, DC: APA Books, 2006, pp. 35–50.

[14] P. C. Rasker, "Communication and performance in teams," Ph.D. dissertation, Faculty of Social and Behavioural Sciences, University of Amsterdam, 2002.

[15] J. D. Lee and T. F. Sanquist, "Augmenting the operator function model with cognitive operations: Assessing the cognitive demands of technological innovation in ship navigation," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 30, no. 3, pp. 273–285, 2000.

[16] M. Neerincx, "Cognitive task load design: model, methods and examples," in *Handbook of Cognitive Task Design*, E. Hollnagel, Ed. Mahwah, NJ: Lawrence Erlbaum Associates, 2013, pp. 283–305.

[17] M. R. Endsley, "Measurement of situation awareness in dynamic systems," *Human Factors*, vol. 55, no. 4, pp. 65–84, 1995.

[18] U.S. Navy. (2012) RQ-21A Integrator. Retrieved June 17, 2013 from Naval Drones. [Online]. Available: http://www.navaldrones.com/Integrator.html

[19] A. Luijendijk, M. Brodeki, A. A. F. Bloemen, and H. F. R. Arciszewski, "Scenarios and vignettes for the unmanned systems programme V1340," Netherlands Organisation for Applied Scientific Research (TNO), Tech. Rep., 2013.

[20] C. R. O'Donnell and F. T. Eggemeier, "Workload assessment methodology," in *Handbook of perception and human performance: Vol. II. Cognitive processes and performance*, K. R. Boff, L. Kaufman, and J. P. Thomas, Eds. New York: Wiley, 1986, pp. 42.1–42.29.

[21] F. R. H. Zijlstra, "Efficiency in work behaviour: A design approach for modern tools," Ph.D. dissertation, Delft University of Technology, Delft, The Netherlands, 1993.

[22] J. A. Veltman and A. W. K. Gaillard, "Physiological indices of workload in a simulated flight task," *Biological Psychology*, vol. 42, pp. 323–342, 1996.

[23] R. Van der Kleij, R. M. Paashuis, and J. M. C. Schraagen, "On the passage of time: Temporal differences in video-mediated and face-to-face interaction," *International Journal of Human-Computer Studies*, vol. 62, pp. 521–542, 2005.