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Evaluation of Human Performance in the Operation of a UAV in a Joint Operation Scenario with Troops on the Ground

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Unmanned Aerial Vehicles (UAV) have been applied more actively in the defense environment against terrorism since 2001. This environment was conducive to developing the Unmanned Aircraft System (UAS), generating the basis for the concept of the so-called mosaic warfare. This concept is the main guide for the design and future use of UAS, determining the design of user interfaces in Ground Control Stations (GCS). Due to the change in the piloting paradigm caused by the increase in the operational capacity and safety of the crew, questions arise related to the suitability of the Human-Machine Interface (HMI) to decrease mental workload. The objective of this research is the investigation questions related to the pilot's workload and the possibility of the total operation of a UAS by only one individual. To answer these questions, an HMI prototype was built to emulate the operation of a UAS. A simulated operation of combat is defined for the investigation. Each operator flew two times, each one with different targets, with two of three settings: one operator using the manual interfaces, one operator using voice command, one operator, and one pilot. The workload assessment was made using ECG sensors and an ISA questionnaire. The ECG results showed that the ECG had consistent results only in the second flight. This may happen because of training was not long enough. The ISA results reported no conclusions.

Keywords: Human Performance, UAV, Physiological Responses, Joint Operation.

1. Introduction

Unmanned Aerial Vehicles (UAV) have been used since the Second world war in subscale aircraft tests; however, it has been applied more actively in the defense environment since 2001 (Singh (2015)). During the development of these vehicles, many sensors, connections enlaces, and different modes of operation were made, and the result of this defined the Unmanned Aircraft System (UAS), developing the basis for the concept of mosaic warfare (Haystead (2020)). This war concept is the main guide for the design and future use of UAS, guiding the concept of Human Machine Interface (HMI) in Ground Control Stations (GCS).

With the increase in operational capacity and crew safety, questions arise regarding the suitability of the HMI to increase situational awareness due to the change in pilot interaction and work. The research's objective is to investigate questions about the pilot's workload in three different scenarios and the possibility of command and management of the sensor of a UAS by only one individual. To investigate these problems and issues, during the Air Domain Study (ADS) project, a GCS was built with an HMI prototype to emulate the operation of a UAS, in which scenarios and tasks are defined (Hobbs and Lyall (2016)).

The HMI prototype experiment treated in this research, scenario 2, is part of a sequence of scenarios developed to investigate and test the HMI focused on operating a Medium Altitude Long Endurance (MALE). The test involves operating a UAS during a search, identification, and classification mission in the Amazon environment. The experiment is divided into two rounds; in one, the volunteer will act only as a Sensor Operator (SO), being responsible for detecting and identifying targets in an area of interest, and in the other, he/she will accumulate the role of Pilot (1P), having to command the aircraft according to the mission control guidelines. When the volunteer occupies the role of 1P, he can use the fully manual interface or voice commands for the entire mission to navigate the aircraft (Contreras et al. (2020)). The objectives of the assessment will be to identify the variation in performance resulting from the accumulation of functions and to evaluate the impact of an alternative HMI on the conduct of the mission.

For the execution, the experiment is sliced into three stages:

(1) The first one is the scenery and theoretical instruction presented through an instructional video;
(2) The second will be training, in which the volunteer will operate the UAV in the simulation station of the ADS project to become familiar with the system interfaces and with the mission, flying in a training environment;
(3) Finally, the third stage will be the performance evaluation, in which the volunteer will have to operate the aircraft in a simulated conflict scenario in two different rounds.

2. Scenario description

To start this scenario, a fictional story about the primary mission executed with UAS in Brazil was created.

Concerned about criminal activities on the border of Brazil, the Federal Government initiated an operation to mitigate these activities. In this operation, a squadron of UAVs from the Brazilian Air Force was activated to supervise an area of interest.

During the operation, a hijacker group approached Village 0 in boats and attacked the area used as a base for the operation, and an official was kidnapped. Observers reported that the boats made their way up the river in a northerly direction. Brazilian Army units were tasked with carrying out a search along the river, while the Brazilian Air Force was responsible for supporting such units with the UAV. The volunteer operator is the military assigned to the mission.

The timely positioning of the UAVs close to where the incident occurred allowed for their quick deployment after the authorities were kidnapped. The volunteer operator receives the initial order to take off and head towards village

0. Additionally, two vessels from the Brazilian army, which also participated in the operation, were engaged. Two operational detachments, each consisting of twelve men, began searching the river.

The mission is to support Brazilian Army units that will carry out a search along the river. Since they do not know the whereabouts of the kidnappers, these soldiers will make stops in the existing villages on the banks of the river to collect information. The operator will monitor such locations, detecting and identifying people and possible enemy settlements before the soldiers come to the villages. All the scenery is executed on the HMI ground station infrastructure.

3. Ground station infrastructure

For making an HMI with the maximum representativity, some GCS were studied. The crew architecture normally used in a UAV classified as MALE consists of One Pilot (1P) and One Sensor Operator (OS) (Macchiarella and Mirot (2018)); however, for the experiment performed in this work in some rounds, only one operator is used to the execution of both piloting and OS functions.

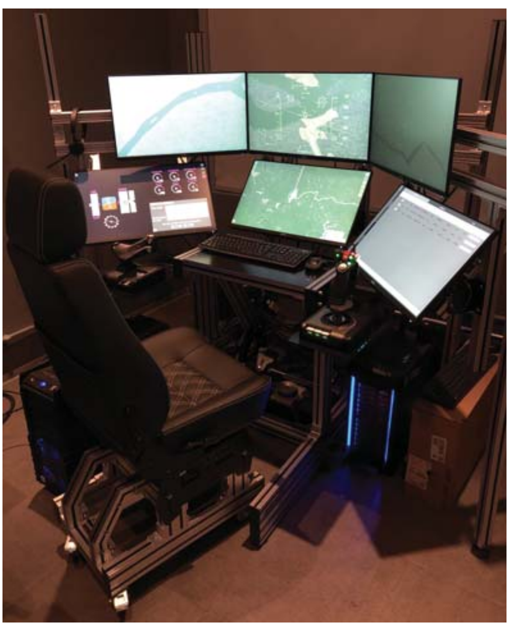

Fig. 1.: Single operator GCS.

In experiments with two crew members, volunteer operators will always act as OS; the pilotage will be in charge of one of the members of the project. In experiments with a single crew member, volunteers will accumulate roles. There is a single station like the one in Figure 1, which volunteer operators will always use. Project members will use a simpler station just for piloting. The responsibility of each person in operation is:

(1) 1P is responsible for communicating with mission control and moving the aircraft.
(2) The OS is responsible for operating the UAV camera and reporting detected and identified targets to mission control.

Fig. 2.: GCS controls.

According to Figure 2, the station comprises six monitors and inceptors; the legend about the number and letters is described below:

- The top three screens provide the operator with a 120° view of the UAS camera, and the down three screens provide the control and mission monitoring of the UAV.
  (1) The Left up monitor is a part of the 120° compose, without zoom possibility. It is used to improve the situational notion.
  (2) The central up monitor features a Head-Up Display (HUD) with zoom properties. It is used to view with more detail the targets of the mission.

(3) The Right up monitor is a part of the 120° compose, without zoom possibility. It is used to improve the situational notion.
(4) The lower left screen displays the aircraft's instruments and sets the autopilot parameters.
(5) The bottom center screen exhibits the map of the mission area.
(6) The bottom right screen takes the list of control points and points of interest.

- In front of the operator, there are input controls.
  - A Sidestick that allows you to control the aircraft manually, direct and lock the camera, change between visible and infrared images, and mark targets of interest.
  - B Thrust level adjusts the UAV acceleration in manual mode, the camera's zoom level, and active voice command.
  - C The pedals are used during the manual flight for control lateral acceleration.
  - D The mouse and keyboard input the navigation data like waypoints, velocity, and altitude.

Using the map of the area, on the control points screen, or through voice commands, the pilot can designate coordinates for UAS displacement, control the altitude and speed of the aircraft, establish circular orbits with a customized radius around a point, and mark locations of interest. Although the controls are fully functional in manual mode, during the mission, the manual control of the aircraft will be disabled. All piloting will be carried out by entering control points and modifying the parameters of the autopilot.

4. Programs implementations

The developed software was based on scripts and block diagrams in Unity (Haas (2014), MatLab (Inc. (2022)),(Documentation (2020)), and FlightGear (developers & contributors (developers & contributors)) software with communications between them. Two lines of communication were adopted using User Datagram Protocol (UDP). The first communication line connects Matlab\Simulink software with FlightGear, and the second communication line transfers data between Matlab\Simulink and Unity software.

The dynamic model of the aircraft used for the experiment was developed in the FlightGear software, with the entire inertial and aerodynamic modeling arrangement, as well as the graphical interface for displaying the scenery, 3D models of the aircraft, and scenery items used during the experiment. The Unity software is used to develop a secondary interface that operates by receiving data from Matlab/Simulink to display to the pilot all the interfaces necessary for piloting the UAV, maps, control modes, and direct actions on the aircraft, such as landing gear commands.

The MatLab/Simulink software is used as a simulation and aircraft manager, in which the flight modes used in the aircraft are encoded in this portion of the simulation, as well as the external inputs originating from the pilot.

5. Human factors measurement

This experiment used the operator's mental workload to evaluate the HMI. This mental workload was inferred using electrocardiogram (ECG) sensors as a physiological data source and an Instantaneous Self-Assessment (ISA) as a subjective data source (Sarmento et al. (2022)).

According to Charles and Nixon (2019), the heart rate (HR) and heart rate variability (HRV) are sensitive to mental workload variations. If the mental workload increases, the HR also increases, and the HRV decreases. The ECG data were processed using a Python algorithm (using the Pandas (pandas development team (2020); Wes McKinney (2010)), Numpy (Harris et al. (2020)), Matplolib (Hunter (2007) and Seaborn (Waskom (2021)) packages), to organize and plot the data and the software Kubios HRV Scientific (Tarvainen et al. (2014)) to analyze the ECG signal. The data was organized, analyzed first on Kubius to get the RR intervals, performed a pilot data standardization (Cortes et al. (2022)), and finally a second time on Kubius to gather the ECG features. The ISA data was processed also using Python to organize but also to calculate the mean and the standard deviation.

ISA is an assessment technique developed to detect the activity's workload in real-time. This technique was developed by the National Air Traffic Services (NATS) to measure air traffic controllers' mental workload. In this technique, the participant, during the activity, self-rates the workload from 1, when the participant is feeling underutilized and with high-spare capacity, to 5, when the participant is struggling to follow the full activity. (Jordan and Brennen (1992))

Both data had their variance tested using an Analysis of Variance (ANOVA) with three factors, which are the flight number, the flight setting, and the mission segment, and their data plotted in a boxplot graph.

6. Experiment

The experiment began when the operator watched the instructional video that was sent when they scheduled the experiment appointment. On the day of the experiment, the operator was trained on how to operate the UAV and familiarize himself with the simulation station. At the end of the training, it was asked if the operator felt ready for the experiment and the experiment only advanced if he/she was ready. After that, an informed consent term was explained and given to the operator to read and sign. Then the sensors were installed on the operator, and a baseline signal with 5 minutes of data was gathered.

At this moment, the operator is ready to perform the two flights. For each operator, a combination of two flight settings was randomly defined. These settings are one operator, two operators, or one operator with voice command. Each flight is divided into seven segments: Village 0; Between Village 0 and 1; Village 1; Between Village 1 and 2; Village 2; Between Village 0 and 3; and finally Village 3. With the exception of the segments between the villages and village 0, the operator must identify targets and execute navigation commands.

After the operator completed the second flight, a second baseline signal was collected, and the volunteer was relieved of the experiment.

The experiment was performed with 24 volunteers, 19 men, and 5 women. These volunteers have different backgrounds. 14 of them had experience with piloting (being aeronautical engineers, students, or military). The setting of each flight was previously randomly defined following the best practices of design of experiments (Mongomery (2017)).

7. Results and discussion

7.1. *ECG results*

Table 1 shows the results of the ANOVA for the HR. It shows that the setting and the combination of setting and flight statistically cause an impact on the heart rate. In the boxplot of Figure 3 plotted the average (orange line) and the distribution of the HR for each flight and setting. It is possible to notice the influence shown by the ANOVA.

Table 1.: Analysis of variance of the impact of the independent variables impact on the HR

Source	P-Value
Segment	1.000
Setting	0.036 **
Flight	0.342
Segment + Setting	1.000
Segment + Flight	1.000
Setting + Flight	0.009 **
Segment + Setting + Flight	1.000

Inside Table 2 and Table 3 are the results of the ANOVA for the HRV and the ratio between the low and high power frequencies (LF/HF). For both features, the only independent variable that had some influence on it was the combination of the setting and the flight.

7.2. *ISA results*

Table 4 shows the results of the ANOVA for the ISA questionnaire. It shows that the setting and the combination of setting and flight statistically cause an impact on the ISA score. In the boxplot of Figure 6 is represented the distribution of both

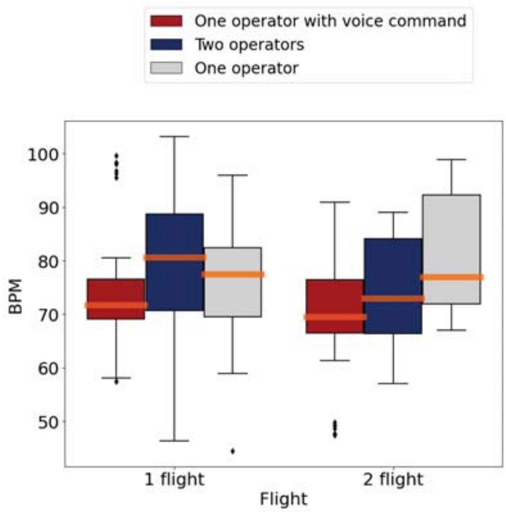

Fig. 3.: HR Boxplot grouped by flight and settings

Table 2.: Analysis of variance of the impact of the independent variables impact on the HRV

Source	P-Value
Segment	0.418
Setting	0.715
Flight	0.841
Segment + Setting	0.142
Segment + Flight	0.837
Setting + Flight	0.000 **
Segment + Setting + Flight	0.715

Table 3.: Analysis of variance of the impact of the independent variables impact on the LF/HF

Source	P-Value
Segment	0.931
Setting	0.350
Flight	0.766
Segment + Setting	0.973
Segment + Flight	0.997
Setting + Flight	0.001 **
Segment + Setting + Flight	0.674

the average and the standard deviation ISA values and is possible to see that the differences between the averages are small and their distribution are

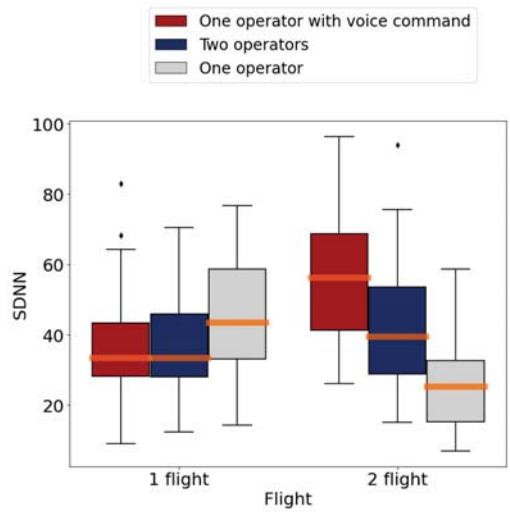

Fig. 4.: HRV Boxplot grouped by flight and settings

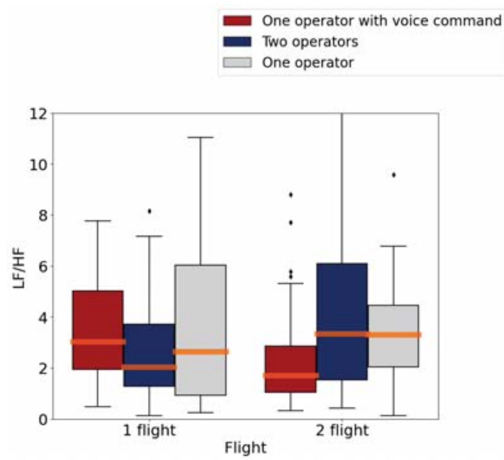

Fig. 5.: LF/HF Boxplot grouped by flight and settings

similar to each other

These results show that, besides the fact that the experiment did not reveal a statistical difference between the different demands imposed by the segments of the simulation, it also show that the ECG features were not conclusive.

7.3. *Discussion*

The ECG results show a non-conclusive result. Despite the ANOVA (Tables 1 to 3) pointed out

Table 4.: Analysis of variance of the impact of the independent variables impact on the ISA

Source	P-Value
Segment	0.985
Setting	0.993
Flight	0.624
Segment + Setting	0.950
Segment + Flight	1.000
Setting + Flight	0.624
Segment + Setting + Flight	0.821

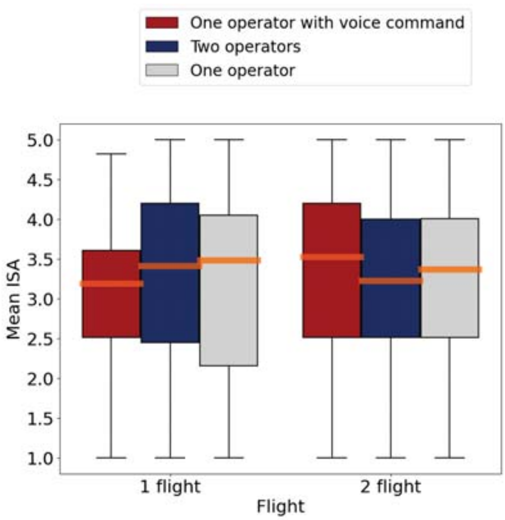

Fig. 6.: ISA average Boxplot grouped by flight and settings

that the setting and, especially, the combination of setting and flight has a statistical impact on the HR, HRV, and the LF/HF, Figures 3 to 5 show a couple of divergent conclusions.

While the HR boxplot shows that in the first flight, the couple lower and higher mental workloads were the *one operator with voice command* and the *two operators*, for the HRV were the couple *one operator* and the other had virtually the same behavior, and for the LF/HF it was the *two operators* and the other two settings.

The second flight has more consistent results. The results found in both the HR and the HRV are the same, the lower mental workload was with the *one operator with voice command* and the higher mental workload was with *one operator*. The LF/HF lower mental workload is the same as the other two but the higher mental workload is not possible to differentiate between the *two operators* and the *one operator* settings

The ISA results did not show any influence from the independent variables.

8. Conclusion

This research aimed to investigate the operator's mental workload and the possibility of only one operator in a GCS. The ECG's analysis showed that the second flight had more consistent results. That could mean that on the first flight, the operators were still learning how to operate the station. If we take only the second flight analysis, we would say that, during the experiment, the setting which caused the lowest mental workload was the *one operator with voice command*, and the opposite was the *one operator*. The ISA score was inconclusive.

For future analysis, it is recommended to ”force” a bigger training. Maybe add to the experiment one extra repetition/scenario/setting that trained the volunteer without he/she knows about it.

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