FMS for Unmanned Aerial Systems: HMI Issues and New Interface Solutions

Luca Damilano · Giorgio Guglieri · Fulvia Quagliotti · Ilaria Sale

Abstract To integrate UASs in the NAS, an improvement in navigation, planning, communication and 4D trajectory control capabilities is mandatory. A way to obtain this enhance is to adopt a Flight Management System. A FMS for an UAS has some differences with respect to one for a manned aircraft, in terms of architecture and performed functions. In particular, from HMI point of view, the specific UAS human factor issues shall be added to the current manned FMS interface lacks. Starting from these considerations, a new FMS HMI for the Alenia Aeronautica TCS has been developed, using as data entry devices two touch screens.

Keywords FMS · UAS · Touch screen · GUI · HMI

List of Acronyms

BIT	Built in test;
BLOS	Beyond line of sight;
FAA	Federal Aviation Administration;
FMS	Flight Management System;
FOV	Field of view;
GCS	Ground control station;
GUI	Graphical user interface;
HMI	Human machine interface;
HOTAS	Hands on throttle and stick;
HIS	Horizontal situation indicator;
IAF	Italian Air Force;
LOA	Level of automation;
LOS	Line of sight;
MALE	Medium altitude long endurance;
MCDU	Multifunction control display unit;
NAS	National Airspace System;
NASA	National Aeronautics & Space Administration;
RAFIV	Reformulate access format insert verify;
SMAT	Sistema di Monitoraggio Ambiente e Territorio;
STANAG	Standardization agreement;
TCS	Tactical control station;
UAS	Unmanned aerial system;
UAV	Unmanned aerial vehicle;
USAF	United States Air Force

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1 Introduction

To integrate UASs in the National Airspace System, an improvement in navigation, planning, communication and 4D trajectory control capabilities is mandatory. A way to obtain this enhance is to adopt a Flight Management System (i.e. the system that manages on manned aircraft navigation, flight planning, performance calculation and optimization, guidance and communications). The FMS has been used by airliners since the 1980s and it can give a great improvement in the UAS operational performances, with a series of modifications that take into account the peculiarities of the unmanned systems. The main FMS functions (like the navigation management and flight planning), have yet been performed by the current UASs, but the related performances are in most cases poor with respect to airliners. Besides there is not a good level of integration between these functions offered by a FMS adopted for unmanned aircraft. At this purpose, some tests have been done by General Electric, AAI and US Army in the December 2009 integrating a FAA certified FMS on a Shadow 200. These results were promising [1].

From the Human Factor point of view, the FMS raises several issues, since the unmanned system HMI problems are added to current airliner interface limits. The GCS HMI varies significantly from the traditional manned aircraft cockpits, with also changes in the user role, that shifts from pilot to system operator. In particular the interfaces vary significantly with the Level Of Automation and the specific vehicle controlled (e.g. external vs. internal operator). A key point is that the actual GCSs are perfectible from this point of view, since the human factors are still one of the main mishap causes. This, in particular, is mandatory for the integration of the UAS in the NAS. In fact NASA has recently started a specific research program with particular care on the Human Systems Integration [2, 3]. A further reason to improve the current HMI configuration is the need of greater interoperability according to the STANAG 4586 [4]. This regulation potentially requires for a GCS the capability to control several different UAVs at the same time, with the consequent challenges for the FMS.

In this paper the preliminary results obtained by a research activities done jointly by "Politecnico di Torino" and "Alenia Aeronautica Spa" about the development of a FMS for UAS are reported, considering as reference a fixed wing MALE aircraft with a large fixed-based TCS. In particular, the new HMI solutions are presented.

The results of the study are general and can apply also to the SMAT project, i.e. a joint research between industries and universities (in which the Politecnico di Torino is a partner and Alenia Aeronautica is the leader) that aims to develop an integrated systems with UASs of different classes to monitor the Piemonte Region, in the North West of Italy.

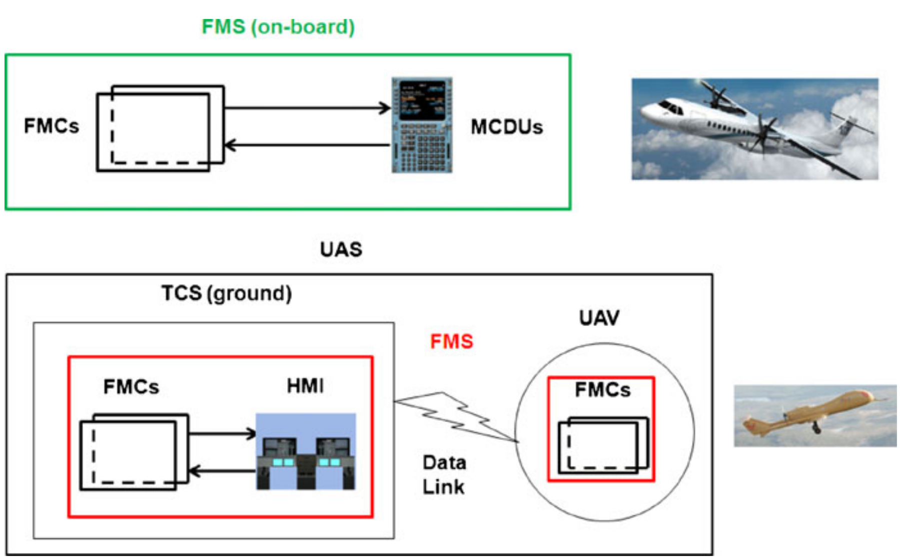

Fig. 1 Differences between manned aircraft and UAS FMSs

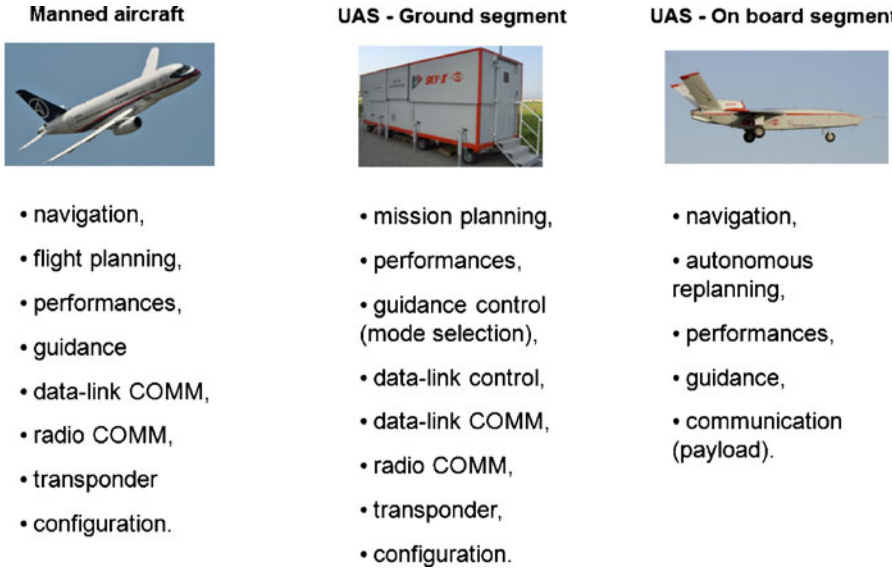

Fig. 2 Manned aircraft and UAS FMS main function comparison

2 FMS for UASs

In general a FMS consist of two or more computers (FMCs) and an interface with the operators. The interface presents different displays and panels (e.g. the navigation display and the autopilot mode control panel), with the MCDU as primary data entry device. While on a manned aircraft the whole system is on board, on UAS part of the FMCs plus the HMI in the ground segment (GCS) and the remaining FMCs on board; they are linked together by the data-link. Moreover, according to the STANAG 4586, the ground segment shall be able to interface with different vehicles (also several at the same time) (Fig. 1).

Over the system architecture, there are also differences in the performed functions and in the allocation between the ground and on board segments. In particular, many functions can be performed in the two segments, with the tendency to allocate most functions on board to increase the LOA. In the figure below a possible division between the main FMS function is represented (usually there are also secondary functions specific of each application, here not considered) (Fig. 2).

The FMS HMI shall permit to the operator to set all the data relative to these functions and to monitor the system behavior.

3 Need of Human Factors Improvement for UASs

UASs have a very low reliability with respect to all categories of manned aircraft (fighters, liners, commuters and general aviation), as shown following table representing data relative to the US UASs [5, 6] (Table 1).

The reasons of these poor performances are different: airframe systems/engine fails, human factors issues, lack of operator training, procedure violations and so on. In particular the main mishap reasons are the mechanical failures, followed by the human factors (the data are always referred to the USA fleet) [5, 6] (Table 2).

Analogous data are available for the Israeli UASs, with 60% of mishaps due to airframe systems/engine fails and 22% to the human factors.

Table 1 Class A mishap rates per 100,000 flight hours

UAV mishaps	Manned aircraft mishaps
Predator—32[a]	F16—3
Pioneer—334[a]	General aviation—1
Hunter—55[a]	Regional commuter—0.1
	Large airliners—0.01

[a]Much less than 100,000 flight hours (2004)

Table 2 UAV mishap causes

UAV mishap cause	Percent
Airframe systems/engine	62
Human factors	17
Communications	11
Miscellaneous	10

The influence of human factors on mishaps varies according to the specific UAS considered: ranging for example from the 21% of the Shadow to the 67% of the Predator (2004) [7].

The term "human factor" involves several aspects: automation interaction, display design, procedures violation, lack of operator training, landing and take off errors and so on.

Integrating a FMS with the relative interface shall help to reduce this high mishap rate, taking into account all the related accident/incident causes to design an improved HMI.

4 Human Factor Challenges for UAS

The physical separation between vehicle and operator introduces several human factor issues that make the design of the interface extremely different from an aircraft cockpit. Many of these issues are directly related to the FMS interface, but since it is integrated in a more complex HMI, it is more appropriate to consider the HMI as a whole. These challenges are:

(a) *Different functions allocation between user and automation*: the functions allocation between user and automation is different with respect to the manned aircraft, especially in the case of autonomous UAV or control of several vehicles by a single GCS. Besides for the UASs some specific functions (not present on manned aircraft) are provided, like the capability to wipe out the on board computer memory for the Predator [7, 8]. Moreover a single UAV can be able to operate with different level of automation, for example switching between manual, semiautomatic and full automatic modes. This fact increases the importance of a correct human–automation interaction, therefore HMI design shall consider the relative problems.

(b) *Huge disparity in LOA*: the current UASs are very different in level of automation, ranging from vehicles controlled manually by the user to semi and full autonomous ones. Besides, different LOA are possible for a single UAV. This fact complicates the design of an interface, since different feedbacks, display layouts and controls shall be provided according to the implemented automation. This is particularly true for a fully interoperable GCS. Also operator training issues play an important role at this purpose.

(c) *Lack of sensory cues*: with respect to a manned aircraft, where the pilot is embedded in the vehicle that is controlling, the GSC operators suffer the lack of several sensory cues: ambient visual input, kinaesthetic (experience of body position, weight and body movement provided by tactile sensors), vestibular (sense of balance and equilibrium provided by the inner ear) and auditory information [8, 9]. These lacks potentially reduce the user situational awareness. To avoid this risk, a proper display design shall be adopted to provide to the operator the necessary information. It is particularly true for the remote manual control of the UAV that needs an imagery of the environment from an on board camera, with all the limitations due to the limited FOV, the image resolution and refresh rate (also constrained by the data-link bandwidth). Besides, the lack of sensory cues can be a problem also for more automatic UAVs, since for example the operator does not have a direct sensory feedback of the turbulence offset (detectable only from a delayed camera imagery). Several solutions have been developed to solve this problem: audio warnings (standard for the manned aircraft and useful to improve the awareness of an alert offset), multisensory displays (e.g. tactile feedback, force feedback on the control stick, spatial audio cueing, speech control, etc.) and synthetic vision. Nevertheless for the last two technologies further research activities are needed to assess their real benefits [8, 9].

(d) *Information overload/boring*: a possible risk of sensory cues lack is that the operator could be overloaded with too many information to contrast its isolation from the vehicle. Considering also that almost all information are provided on the displays (visual sensory channel), this can cause a high workload for the operator [10]. On the contrary, if the operator is not involved in the control loop, he/she will be bored, with a reduced capability to withstand a sudden event.

(e) *Latency*: the latency introduced by the datalink makes more difficult the manual control of the vehicle especially during take-off and landing. This is particularly true in case of BLOS control via satellite (in fact it is not used near the ground). This is a further reason to increase the LOA of UASs.

(f) *Long duration missions*: several typical UAS missions (e.g. monitoring, searching, communication relay, etc.) have a long duration (even several days in the future), with the consequent need of a proper crew turnover to guarantee always a good level of the human performances. Besides, the interface design shall concur to provide the correct crew workload and situational awareness, considering also the human weakness to maintain a proper vigilance for long time period with low task demands (typical case of cruise phases of monitoring, search and so on) [8].

(g) *Handover procedure*: the handover is the procedure for passing the control of a UAV/payload from a GCS to another one, from an external pilot to a GCS internal one or from a crew to another one in the same GCS. From the procedural errors point of view, this is critical for the safety, with several mishaps in the past [7, 11]. On this subject, the STANAG 4586 is useful to implement the handover among different GCSs, providing a set of standard messages for the control exchange, that helps to define a procedure for each specific system.

(h) *Lack of standardization*: there is a lack of standardization in the GCS HMIs due to huge disparity in LOA between UASs and the relative low know-how (at least with respect to the manned aircraft). So there are not specific standards and guidelines that help the design of the new systems.

(i) *Lack of application of manned cockpit know-how*: most of the current GCSs do not consider (or consider marginally) the experience matured in a century of manned aircraft flight and mishaps. The GCS must not be equal to a cockpit for all the reasons listed above, but some basic HMI rules and experiences obtained from the manned aircraft background shall be considered within the context of the UASs. Some studies, in fact, confirm that the present GCSs are not properly designed from the human factor perspective [7, 9]. This is probably also due to the fact that several of the current UASs have been designed by not primarily aircraft manufactures [7].

(j) *Lack of standardization of user qualification and training*: at the moment there are not specific rules that state the figure, background, training and qualification of the UAS users. In particular for the control of the vehicle some air forces (like IAF) consider only rated military pilots, while others (e.g. USAF) employ both rated military pilots and not-flying officers (in most case with a limited flight training on manned aircraft [12]). In particular the use of rated pilot can be useful in the case of UAVs manually controlled, where his/her flying skills are directly exploited. Considering the manual control by a remote pilot, inevitably, the displays layout tends to be similar to that of cockpit displays with some particularities typical of the unmanned systems. Nevertheless the development trend of the UAS is more toward greater autonomy, with a different role of the user, shifting from the figure of a pilot having direct control of the vehicle to a system operator able to control one or more UAVs simultaneously with higher level commands. In this case the flying skills are not needed and the interface is no longer related to cockpits (e.g. stick, throttle and pedals are not need). To conclude: the design of an interface is strictly related to the role, skills and background of the final user, with a tendency toward more autonomous systems.

5 Human Supervisory Control

The function allocation between human and automation can be detailed considering the paradigm of "Human Supervisory Control", according to which the operator is a remote supervisor and manager of one or more UAS, interacting intermittently with one or more computers [13, 14]. This "computer-mediated control" is typical of several applications like ATM, power plants, several military systems, modern aircraft (e.g. an airliner in cruise), space systems, and it is particularly suitable to describe the control of an unmanned system.

The HSC can be broken up in four nested control loops [13, 14] as shown in Fig. 3.

The innermost loop represents the basic flight control of the UAV and it is directly related to the specific vehicle dynamics. The second loop is related to the navigation control in terms of planning (route decisions, no-fly-zones avoiding, modifications of an existing route, etc.), execution of the action decided and route heading (track) determination. The third loop finally is the highest level one, devoted to the management of the mission and of the payload. If one of these loops fails, also the higher level loops will fail. Parallel to the control loops there is a continuous system health and status monitoring that involves all previous loops. In general, each loop can be demanded to the operator or to the automation.

As said before, the tendency is toward a greater automation: almost all current MALEs have an autopilot system and many of them have also advanced automatic navigation mode (e.g. the Global Hawk flies its missions from take-off to landing in automatic way [9]). The FMS, in particular, permits an automatic (autonomous in the future) management of the two inner loops. Therefore the operator is able to concentrate himself on the higher level of mission management and monitoring of automation. This requires knowledge-based decisions and in general it is difficult to allocate it to the automation [15].

In conclusions, by adopting this way, a single operator is able to control several UAVs at the same time.

6 Automation Interaction Problems

The introduction of the automation aims to two objectives: reducing the physical workload of the operator and increasing the safety, replacing the humans in the execution of prolonged and repetitive/critical tasks. An example is the autopilot that relieves the pilot from the need to maintain a continuous manual control of the aircraft, and helps him in the execution of critical operations like the landing in marginal weather conditions. Despite this, there are situations in which, on the contrary, the automation increases the cognitive workload of the operator, and reduces the global system performances and potentially leads to mishaps. This is due to a poor level of integration of the automation with the operator that shall be always adequately maintained inside the control loop. As elements of a complex system, in fact, human and automation shall be optimized one respect to the other to provide the best effectiveness.

This problem has been extensively considered for manned aircraft in the last decades after some serious accidents, but for the UASs there are still some open items. In the case of unmanned systems, in fact, the interaction with the automation

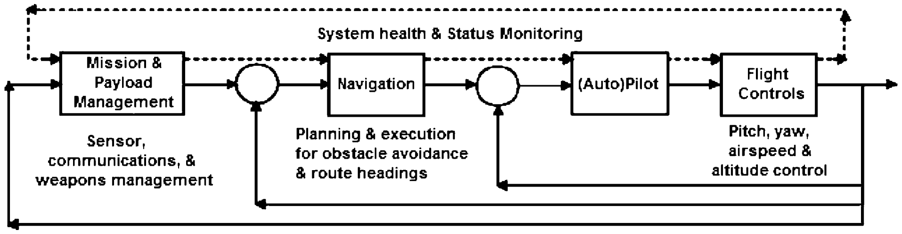

Fig. 3 Nested control loop for HSC of UASs [13, 14]

is more complex for the reasons listed before. In particular these problems are strictly related to the FMS, that is the core of the automation. The main issues of the human–automation interaction are [8, 9, 13–20]:

(a) *Mode awareness/confusion*: the terms "mode" can be defined in several ways and in general is referred to a particular state of the system associated to a unique behavior. Considering the block diagram of the Human Supervisory Control, different modes are associated each control loop: autopilot, navigation, payload, mission management and system monitoring. Unfortunately, the increase of the automation in a system is frequently associated to a decrease in the transparency of the automation behavior, with a following reduction of the operator situational awareness. This fact is know as "mode awareness/confusion" and is characterized by a misunderstanding of the current active mode or a lack of comprehension of the behavior of the automation in a certain mode. In both cases the operator could do an inappropriate request to the system or in general could do correct action for his/her situation perception, but incorrect for the actual mode, with potentially serious consequences (like some accidents involving airliners in the 1990s). This problem is due to several factors as the complexity of the system and the poor interface design. Considering as an example a traditional airliner autopilot, there are in average 25 different possible modes, with consequent increase of the mnemonic load for the operator that shall remember the behavior of each of them. Moreover, in the advanced navigation modes (managed by the FMS) there are frequently automatic mode changes that are not easily perceived by the pilot (a recent research indicates that a percentage between the 30% and 40% of them are in average undetected), due to the lack of a proper feedback from the system and to an incorrect automation mental model of the operator. In fact, while monitoring a semi-automatic mode (e.g. altitude, vertical speed, heading and airspeed hold) is relatively easy, since the situation can be monitored with the same instruments (altimeter, variometer, HSI, etc.) used in manual flight, to follow a route in automatic mode is more complicated without clear indications of the system behavior due to FMS and autopilot interfaces. The poor automation mental model is due both to the system complexity (e.g. in average a pilot reaches a good knowledge of a FMS after 12–18 months of use) and to the difficulty for the operator to understand the automation behavior, also in the cases where it follows the basic manual flight rules (e.g. the difference between the modes controlling the airspeed with the pitch and the ones using the throttle).
If this is a problem for a manned aircraft, for a UAS it is still more relevant, due to the greater level of autonomy and the different functions allocation between human and automation. It is therefore fundamental to design the system in a way that makes it easy and effective to use, with a proper HMI that provides all information needed by the operator.

(b) *Automation management*: the automation can be managed at two different levels: by consent and by exception. In the first, the operator shall approve each action (i.e. the automation can not take any initiative without the human approval); while in the second the automation gives some time to the operator to reject the proposed action and without a veto it will follow out the action. Management by consent is the more traditional way to use the automation, but to obtain a greater LOA a shift toward the management by exception is needed. To fulfill this requirement the interface shall be designed to provide all needed information to the operator to take the correct decision in a proper time. Some serious accidents due to a poor HMI design, in fact, occurred in the past, like the friendly-fire of Patriot missiles in the operation "Iraqi Freedom". However if the management by exception can be the foreseeable solution for the future military applications, in the case of civil use of UASs the subject is still disputed. For example the FAA asserts that any UAV that flies in the NAS shall be directly controlled by a human.

(c) *Increasing cognitive demand*: as said before, the automation reduces the physical workload of the operator, by replacing him/her in the execution of many manual tasks and increasing at the same time the cognitive workload. The operator, in fact, is more involved in activities of decision making, planning and monitoring, with a shift of his/her role from direct controller of the system to supervisor. In some situations, the cognitive workload can increase too much (cognitive overload), with an important performance reduction and the possibility of mishaps. The HMI is fundamental to reduce this risk, aiding the operator to be correctly inside the control loop.

(d) *Increasing monitoring demand*: the need to monitor the automation behavior and the system status has increased the monitoring demand of the operator. Unfortunately the humans have poor capacity to maintain a high visual attention for more than 30 min, independently by the motivations of the operator. This is particularly true when the automation works correctly, lowering further the operator vigilance, with the risk that he/she can not be able to react properly and rapidly to withstand a sudden event. So the interface shall provide a proper system feedback to help the monitoring and have a good system of alerts that draws the operator attention in case of failures or particular events.

(e) *Unbalanced workload*: the automation reduces the operator workload especially in the mission phases yet characterized by a lower workload, like for example the cruise. On the contrary, in the phases of high workload (e.g. in the proximity of an airport), instead, the automation could increase the operator workload, because it is difficult to use the automation in a reduced time, mainly due to poor interfaces. For this reason, many airlines prohibit their crews to use the FMS in the terminal area. For a high LOA UAS, however, this could be a serious problem and then the HMI shall be designed to make the interactions more user-friendly and immediate.

(f) *Increase crew coordination requirements*: the introduction of the automation in the aviation has stressed the need of a greater crew resource management inside the cockpit. Due to the difficulty to monitor the automation behavior and the possibility of mode confusion, a communication between the crew members about the automation use is mandatory to avoid the risk of a misunderstanding about automation work. This is particularly true for a UAS, especially in the case of control of several UAVs.

(g) *Mis-calibration of trust in the automation*: it is really important for the operator to develops a correct trust in the system automation. The trust is function of several parameters: easiness of use, reliability, interface, and it should be neither too high nor too low. If it is overmuch, it is present the so called "automation complacency", that is a state in which the operator relies too much on the automation, neglecting the signals of an improper work or failure and continuing to use it until the mishap. Vice versa, with a low trust, the operator does not develop a correct relationship with the system and he/she will tend to deactivate (if possible) the automation in case of problems, to take the manual control of the system, also in the cases in which this is not the safer solution (e.g. a landing with reduced visibility). These two situations have caused many accidents in the manned aviation. It has to be noted as for the UASs with a high LOA is not possible to bypass the automation.

To conclude, although the humans have been removed from the vehicle, in the UASs the integration of the operator in the control loop is mandatory, with several human factors issues that can compromise the overall performances and the system safety.

7 Human–Automation Interaction Model

In literature are present several models and theories to describe the interaction between human and automation. In this paper the RAFIV (Reformulate Access Format Insert Verify) model was chosen as reference. It was created by a partnership between Honeywell, University of Colorado (Institute of Cognitive Science) and NASA Ames Research Center. Although it has a general validity, the RAFIV model has been developed with a particular care to the interaction with the MCDU, that is however representative of the interaction with many other interfaces. According to this model, the interface efficiency and robustness are function of the volume of memorized action sequences. The interaction process can be broken down in five different steps [21, 22] (Fig. 4):

(1) *Reformulate*: as a first, the mission task is reformulate into a series of sub-tasks to perform and data to enter in the automatic system. In other words the operator creates a mental description of how the automation will be used to accomplish the mission task. For example a change in the flight plan can be converted into a set of data (new waypoint and its attributes) that shall be entered in the automation.

(2) *Access*: having a clear idea of the operation to do, the operator accesses to the right interface (e.g. a hierarchy of MCDU pages, the autopilot mode control panel, a multifunction display, etc.). This step represents the action that shall be taken on the interface to display the field for the data entry or to orient the operator attention to the correct input device.

(3) *Format*: when reached the right interface, the operator enters the data with the proper format.

(4) *Insert*: when the data have been entered, they are inserted in the correct location. This step is typical of a MCDU, where the data are first typed in the scratchpad and then inserted in the proper field.

(5) *Verify and Monitor*: when a command has been given to the automation, the operator checks if it has been actually accepted, if the automation performs correctly the command itself and if the command was appropriate to accomplish the mission task.

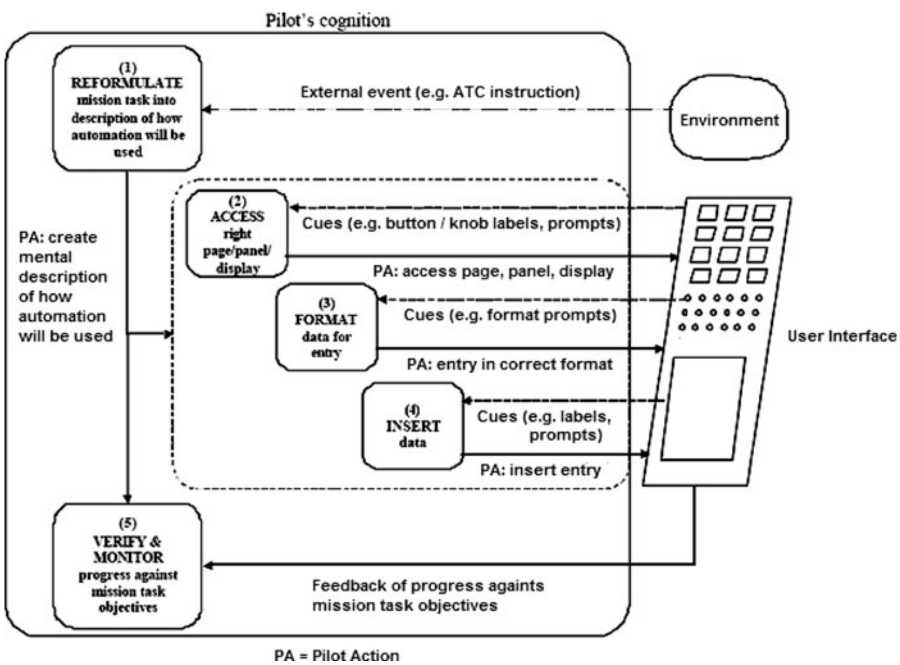

Fig. 4 RAFIV model [21]

Each of the previous steps can be performed by the operator by recalling the appropriate actions from the long-term memory or recognizing them from visual cues provided by the interface [21]. It is demonstrated that the training time for actions that rely completely on the memory is 2–20 times greater than that performed with the aid of visual cues. Besides, the action based on memory recall and performed infrequently exhibit a completion probability lower than 50% [21], with consequent operator skill deterioration. Nevertheless, many current interfaces are lacking from this point of view: considering for example the MCDU of the Boeing B-777 with a sample of 102 mission tasks, 74% of them need memorized action sequences and the 46% occurs infrequently [21].

To summarize, according to the RAFIV model the interaction between humans and automation is optimized when the number of memorized action sequences recalls is minimum [21]. In particular to satisfy these criteria the following guidelines for the interface design can be drawn:

- The interface shall support directly (as much as possible) the mission task execution to reduce the workload related to the reformulate step,
- The operator shall be guided in the interface interaction with visual cues like labels, prompt, dialog boxes, pop up and so on,
- The step of verity and monitor can be simplified displaying to the operator a visual representation of automation state.

8 New Alenia Aeronautica FMS HMI—A General Overview

The research activity has been realized in the development of some FMS interface formats for the Alenia Aeronautica TCS (a so called "Tactical Control Station". This new interface has been designed with the constraints to be compliant to the STANAG 4586 and certifiable by the international civil aeronautics authorities, having Alenia Aeronautica Sky-Y UAS as a first application. The TCS consist of two interchangeable stations: one for the pilot and one for the payload operator. In particular, for the UAV control, the interface permits several LOA, ranging from the manual remote control of the vehicle to advanced automatic modes, according to a complete fulfillment of the interoperability requirement.

Each station has the following layout:

The Main Display is the primary monitoring device for the operator (no inputs can be given trough it), whereas two Touch Screens (10 in.) are used as primary data-entry interfaces with secondary monitoring functions. In particular a Touch Screen is devoted to the safety critical functions and another to the non-safety critical ones. In the central panel are installed some hard-wired controls that require a quick access by the operator. Finally, traditional flight controls are provided: stick, throttle and pedals (not displayed in Fig. 5). The HOTAS controls let the operator to manage some functions in head-up conditions, without releasing the hands from stick and throttle.

The STANAG 4586 requires potentially to display all standard message data and the vehicle specific ones. To accomplish this requirement, it is mandatory to have a flexible reconfigurable interface able to adapt its formats according to the specific vehicle controlled. Therefore the interface shall be designed with a "point and click" interaction philosophy (typical of the GUIs), rather than a traditional cockpit. On the other hand,

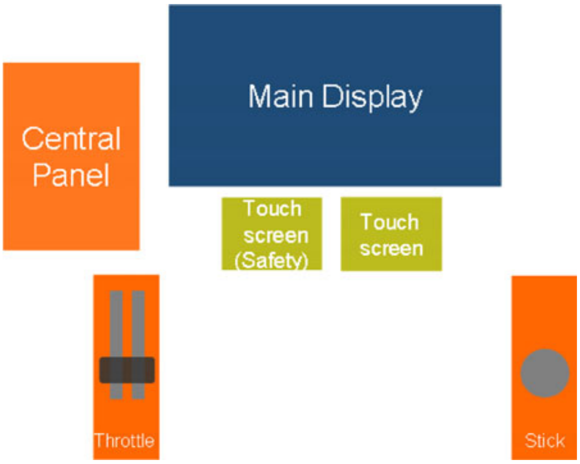

Fig. 5 HMI layout (*right station*)

by maintaining a large number of elements already used for a traditional manned aircraft flight-deck can be helpful to accelerate the certification procedure, since unfortunately there is a lack of specific rules for the UASs and so analogies with the standards of manned aircraft are usually adopted. Moreover, this fact involves also the role, the training and the background of the operator, who could also have no previous flight experience and probably will be more confident with a GUI than a rated pilot could be (on the other hand a pilot could be disoriented when facing an interface different from aircraft displays). This is an additional reason to move toward autonomous system with an operator as user, with the challenge to get from the civil aeronautics authorities the acknowledgement of this professional role and the relative concept of operations.

In the research development the traditional aeronautics background in human factors has been merged with the GUI principle of applications like computers or tablets, taking the advantages of each of them to develop an optimized solution. In particular all the issues above considered have been taken into account.

As regard the FMS interface, part of the related information are displayed on the Main Display, while the data entry occurs in the two touch screens. In particular, for monitoring many information about the vehicle state are displayed both on the Main Display and on the touch screens, while others (in general the details) are present only on touch screens. In order to simplify the interaction, on the touch screens are allocated functions that on a traditional manned aircraft are controlled using different interface (MCDU, autopilot mode control panel, radio panel, etc.). Moreover, in the same format are present both the controls and the system information feedbacks, so that the effects of the given commands can be monitored directly, making easier the execution of a task.

The formats developed in this research activity are hosted in the safety critical touch screen and are relative to the following macro functions (a subset of the list previously reported in Fig. 2):

- autopilot and navigation,
- radio communications, and
- vehicle configuration.

More in details, the following sub-functions can be performed in the related format (Table 3):

The implemented functions give great operational flexibility to the system, obtaining capabilities typical of airliners. This is useful for introducing the UASs in the NAS. In particular, an advanced 4D navigation mode is provided.

Table 3 Developed format functions

Autopilot and navigation	Radio communications	Vehicle configuration
• Mode arming	• Transmitter radio selection	• UAV configuration setting
• Mode engaging	• Receiver radio selection	• On board specific data/ parameter loading
• Autopilot demand arming	• Frequency setting	
• Autopilot demand engaging	• Frequency storing	
• On board route loading (also with the UAV in flight)	• Frequency loading from database	
• Route arming	• Emergency frequencies (121.5 and 243 MHz) quick selection	
• Route engaging	• BIT	
• Destination waypoint changing	• Interphone configuration setting	
• Seeing the waypoints details (name, coordinates, assigned speed or time to arrival, etc.)		
• Making a “Direct to” toward a loiter waypoint		

9 Development Process

For the development of the new interface, the principles of the "User Centered Design" [17] have been adopted, since they permit to obtain a high usability, considering the final user at the center of the design activities. In particular the following process has been followed (Fig. 6):

By fixing the targets, a theoretical study on the requirements of the device by the point of view of the final user (supported also by task analysis) was performed.

During this phase, a research on the HMI challenges for UASs and on the lacks and improvable aspects of the current GCS interfaces was performed and results are those ones reported in the previous pages.

As second step, the HMI layout has been selected, comparing different possible solutions (e.g. touch screens, trackball, keyboard, etc.).

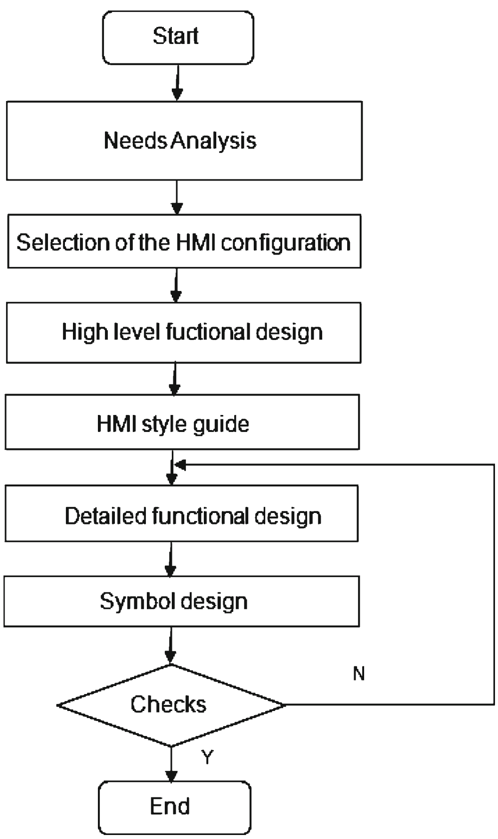

Fig. 6 HMI design process

Then a higher level design has been initiated, either from the functional point of view and from the definition of the style guide, i.e. the general guidelines for the design of the symbols and the interface moding (e.g. color coding, macro push-button categories, characters, etc.).

The Alenia Aeronautica test pilots have been involved since these preliminary steps, with the scope to maintain the users in the design loop. Some of the new functionalities, in fact, have been implemented to meet pilot requirements.

At the end of this phase, the functional and graphics detailed design of the several formats has been carried on. It was an iterative process with continuous checks with the specialist of each system and the test pilots, until the final configuration was defined. In particular, some evaluations in a rapid prototyping simulation environment have been done, obtaining positive feedbacks by the pilots about the graphics layout and interface moding.

At the moment the code is under a development phase. A more complete evaluation will be done when the new FMS will be available in the TCS test environment and during the next flight-test campaign.

10 Use of Touch Screens

The touch screens have been selected by a comparison with other data entry devices like keyboard, trackball, touchpad or a combination of them. The use of touch screens in aeronautics is still at the first stage of application, therefore a limited number of data are available. Examples are: the cockpit of the F-35, a FMS of the Garmin for business jet (under development), studies and prototypes for airliners and regional transport aircraft, and some IPad® and IPhone® tools for general aviation and sailplane pilots. The related technologies have been recently experienced: a great improvement in terms of performance, reliability, size and weight has been obtained. This fact makes really interesting their use, also considering that GCS is a static device on ground application, with low vibration and environmental problems with respect to the on-board ones. Besides, since they are diffused in the everyday life, the feeling of the user with this type of interface has even more increased.

The use of touch screens gives the following advantages with respect to the other options:

- More instinctive interactions,
- Possibility to adopt new types of interaction like for example the scroll movement on the sliders,
- High flexibility and reconfiguration capability since all controls are generated via software,
- The alphanumeric keyboards are displayed only when necessary,
- Greater display dimension with respect to a traditional Multi Function Display, due to the absence of line select keys and fixed keyboards,
- Possibility to have a back-up of the Main Display in case of failures,
- The Main Display is devoted only to the monitoring, without input interactions on it,
- The current UAV state is always displayed in the Main Display, giving the capability to see on the Touch Screens other information about the mission,
- No size issues related to the keyboard, trackball or touchpad positioning.

To decide the formats, the MIL-STD-1472F [23] has been taken as reference for the response areas dimensions and relative distances. In particular, these information are provided distinguishing between alphanumeric keyboard and other functions pushbuttons. Considering the latter, the minimum size (16 mm) is greater than a traditional fingertip pushbuttons size (10 mm for bare finger), but the minimum distance is lower: 3 versus 13 mm (single pressure) or 6 mm (sequential pressures). There is also the same situation for the maximum values. So virtual pushbuttons takes near the same areas of hard wired ones. In current aircraft, the actual size and dimensions could be smaller than the prescribed values, due to specific size limitations. In our works, however, we have followed the standard.

Moreover the virtual pushbuttons are only displayed when needed. With traditional hard wired controls, on the contrary, in some cases, part of the pushbuttons are not used in some formats, and they take away useful place. Together with the lack of fixed numeric keyboards, this gives a great flexibility to the interface, as reported above.

But for new controls, like sliders or scroll bars, no indications are provided by MIL-STD-1472F. The standard, in fact, is not updated for these applications (1999) and a new issue (or another standard) including these new interaction types should be provided. In any case, starting from the given data, some changes have been introduced when needed.

The touch screens, however, introduce also some new problems, due to the fact that the operator does not have a direct feedback if the control has been pushed. As an example, some autopilot mode control panels have rotary knobs of different shapes (square, triangular, circular sections, etc.) for the demand setting (altitude, heading, speed, vertical speed demands), to give this feedback. On this purpose, using the color coding, an indication is provided, but the operator should look at the touch screen to avoid the risk of error. Also for this reason, some critical and quick access controls are still hard wired in the central panel.

The tactile feedback touch screens can be a possible solution, but the technology is still immature, especially in terms of size and installation. Besides, to have a vibration at each touch pressure could be annoying for the operator, with problems related to the fatigue-life of the device. So the tactile feedback could be limited to some particularly critical controls.

Eventually, another possible problem is the following: for example, in case of hard-wired switches, there is a cover safe guard, but it is not present for virtual pushbuttons. To overcome it, different solutions have been adopted: for example a pop-up displayed when the control has been pushed or multiple touch actuations in different positions of the display, according to the MIL-STD-1472F. These solutions, together with a proper color coding for the pushbutton state changes, have been considered satisfactory to provide a correct Situational Awareness by the Alenia test pilots. The tactile feedback is for

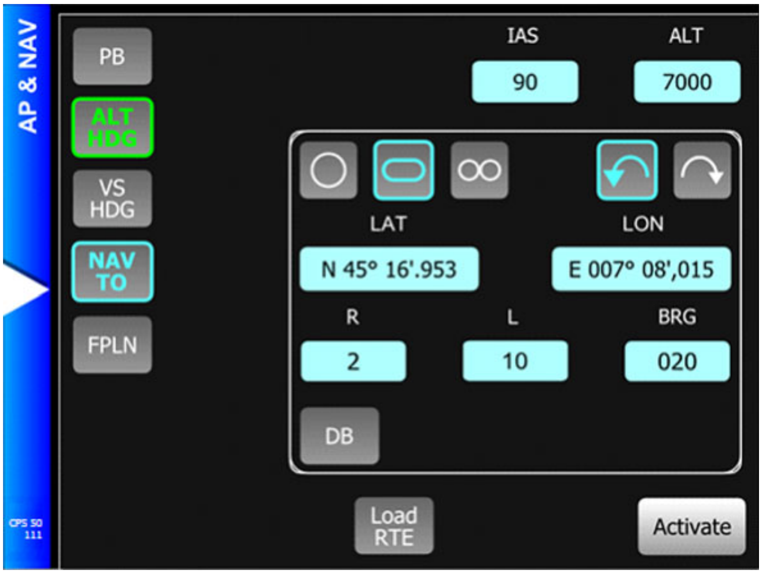

Fig. 7 Example of the autopilot and navigation page

sure useful, but not mandatory for this type of applications (Fig. 7).

11 Main Characteristics of the FMS New Interface

The main characteristics of the developed FMS interface are:

- Different interfaces of manned aircraft (MCDU, autopilot panel, radio panel, etc.) are joined in a single device, in order to simplify the interaction and the system monitoring.
- The interface has a great flexibility, since all symbol set is generated via software, making easy a graphics update.
- Moding (e.g. pushbutton states or specific functions like numeric keyboard opening) and graphics (e.g. general page layout, pushbutton type, color coding, etc.) maintain the greater possible commonality among the different formats to reduce the operator workload.
- The autopilot and navigation modes have been reduced as much as possible, joining basic modes in a single one, to limit the system complexity without any loss of operational capability;
- There are not automatic mode changes.
- The automation and the GUI support directly all mission tasks. In other words, for the functions reported in the Table 3, there are specific controls are devoted to them. In this way the "Reformulate" step of the interaction is consistently reduced and as well as the operator workload.
- The GUI provides a clear direct feedback to the operator of the state of the automation, thanks to the color coding and the graphics, and reduces the possibility of modes confusion (Fig. 8).
- Using the color coding, a feedback of the response message coming from the vehicle is provided (STANAG implementation).
- The GUI guides the operator through visual cues like for example labels, pop ups and dialog boxes. So far the mnemonic load is reduced and the feeling with the interface increases. Just one format can be opened one at one time. In particular pop-ups are used to ask confirm to the operator about some critical

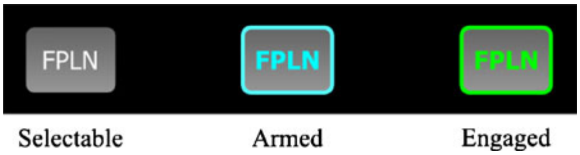

Fig. 8 Autopilot mode pushbutton states

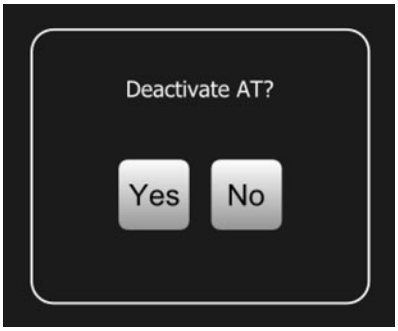

Fig. 9 Pop-up example

controls. To avoid missing/misunderstanding situations, the other page controls are not selectable until the operator gives the acknowledgement to the open pop-up. Moreover, when the operator quit from the page, it automatically closes, annulling the relative action (Fig. 9).

- Safety critical elements like autopilot mode pushbuttons and autopilot demand fields are never covered by other formats (pop-up, dialog, etc.). Taking into account the page dimensions with respect to the other formats ones, this is not a limitation. However, all information about current UAV state are always present in the Main Display.
- The GUI is reconfigurable according to the STANAG 4586.
- The GUI fulfills STANAG 4671 [24] requirements, as it as considered applicable by the EASA policy E.Y013–01 as a base for certification [25].
- The software of the GUI is developed according to the DO-178B.

12 Conclusions

The Flight Management System integration in UAS improves operational capabilities in terms of navigation, planning, communication management and 4D trajectory control, and contribute to open the NAS to UASs. Taking into account the problems of current manned FMS HMI and the human factor challenges typical of unmanned systems, a new FMS interface for the Alenia Aeronautica TCS has been developed. It is compliant to the STANAG 4586 and certifiable by the international civil authorities. In particular two touch screens have been adopted as primary data entry devices. Merging the principles of aviation human factors and of the commercial GUIs, the developed HMI presents innovative solutions to solve the recognized lacks and increases the performances of the system. These results can be applied also to the SMAT project (already mentioned in the introduction of this paper).

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