Implementation of STANAG 4671 Ground Station Standard for Piccolo Command Center

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The advent of Unmanned Aircraft Systems (UAS) represents a major change in aviation operations. No longer is the pilot on-board the aircraft to mitigate certain failures or directly monitor the aircraft. Instead the operator is sitting in a remote station relying on a computer screen to provide him the necessary Situational Awareness (SA) to safely conduct his mission. Due to this, it is extremely important that the interface between the operator and the aircraft system display the correct information in a way that is easy for the operator to view and understand. Standardization Agreement (STANAG) 4671 -Unmanned Aerial Vehicles Systems Airworthiness Requirements- (USAR) is the NATO agreement that defines the minimum airworthiness standards for UAS above 150 kg. This standard has been developed to help integrate the UAS operations between NATO member states. USAR addresses the full scope of UAS operations and this research specifically examines its requirements to ground stations. Cloud Cap Technology's (CCT) Piccolo autopilot provides a powerful tool for controlling UAS and has found use in many civilian and military applications. The Piccolo Command Center (PCC) allows the user to interface with and monitor the state of the unmanned aircraft. However, the ground station does not conform to USAR. A plug-in for the PCC was developed to try to bring it in to as close compliance with USAR as possible. The plug-in is integrated into the standard PCC software through the exposed API such that it can access all of the telemetry. The plug-in monitors and displays this information in accordance with USAR.

I. Introduction

The rapid increase of new UAS entering the market has begun to open questions of integration into the National Airspace System (NAS) here in the United States (US) and abroad. In order for this to occur standards and certification processes similar to those applied to conventional aircraft are being developed by various groups. In the fall of 2009, NATO released STANAG 4671[1] to establish the minimum UAS airworthiness requirements for UAS. STANAG 4671 addresses every aspect of UAS operations from structures to propulsion to operational constraints. This research focuses on providing several software plug-ins to help meet the requirements for ground control stations as prescribed by STANAG 4671.

Among the UAS currently being flown by NATO states are those based around CCT's Piccolo Autopilot. The CCT system consists of airborne and ground-based hardware and software. The airborne component (typically referred to as the autopilot) is closed source and accessing this component would incur significant cost. Furthermore, modifications of the autopilot software would mean it would be unique and as such the tools described in this paper would not be applicable to any other Piccolo user. However, the heart of the ground station, the Piccolo Command Center (PCC) software, can be interfaced to directly via plug-ins written by the end-user. It is this capability that is leveraged in order to bring the PCC into closer compliance with USAR.

II. Determination of Plug-in Requirements

The first step in this research was to determine what requirements of the USAR could be addressed through software interface modifications. The requirements set forth by the USAR for ground stations are defined under "Subpart I – UAV Control Station". This subpart defines the requirements for the interface between the operator and the UAV and the conditions under which this interface is used. Appendix A lists each USAR in this section and how it was addressed during this research. The various requirements are grouped into seven categories: Member State Specific Airworthiness Concerns (MSSAC), Addressed in Base PCC, Physical Requirements, Piccolo

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Limitation, Scope, Ubiquitous, and Mapped to Plug-in.

Most USAR contain elements that would put them into multiple categories. For simplicity the USAR is listed with the category of greatest relevance. Thus a USAR with a MSSAC element and a Ubiquitous element would be listed under Ubiquitous because the Ubiquitous elements need to be considered for the specification of the plug-ins.

The first category, MMSAC, addresses elements such as USAR which require adherence to the requirements of a "Certifying Authority". These requirements were not considered in this research because they are member country specific.

The stock PCC has an extensive interface that has been vetted by the realities of UAS operations for several years. The result is that the stock PCC already adequately addresses many of the requirements of USAR. Those requirements that have already been met by the PCC base design are labeled as "Addressed in Base PCC".

Some of the requirements such as lighting, power, and other infrastructure items cannot be addressed through software interface modifications. There are also numerous other requirements that relate to specific installations or require additional hardware. These are beyond the scope of what can be addressed through the interface and as such are labeled as "Physical Requirements". This category also included airspace integration equipment for communicating with air traffic control.

The broad applicability of USAR also means that it covers components and capabilities that go beyond the abilities of the Piccolo system. Requirements that exceed the Piccolo's capabilities are categorized under "Piccolo Limitation". Some consideration was given to establishing means of controlling these components through the Piccolo, but those solutions involve specific installation changes (i.e. an external sensor connected to one of the Piccolo control lines). These solutions would be unique to each vehicle and installation and as such were not applicable to software plug-in solutions.

The "Scope" category encompasses those requirements that could be addressed with software plug-ins, but whose complexities would make each of those plug-ins a separate research project in their own right. The difficulties and complexities of those requirements are considered beyond the reasonable scope of this research effort, but they are worth exploring in more detail in future work. Specifically USAR 1720 requires that, "Automated mission planning calculations must not lead to unsafe conditions." The PCC does contain a mechanism for automatically creating landing patterns. Development of software to ensure that this plan is always safe represents a significantly difficult challenge. The only other USAR to receive the "scope" categorization was USAR 1787 which requires "automatic diagnosis and monitoring". The complexity of the UAS in conjunction with the reality of limited information makes it difficult for a human to diagnose. The difficulty of training a human for this task is comparatively simple when faced with the difficulty of training software due to the sheer number of possible failures that may occur.

The remaining requirements are divided into two categories; "Ubiquitous" or "Mapped to Plug-in". Ubiquitous requirements were those that could reasonably be applied to every plug-in and should be considered in all the software specifications, such as USAR 1785 which specifies the coloring scheme to be applied to all warning, caution, and safe conditions displayed. Those requirements that could be mapped to specific plug-ins are described in the next section of this paper.

III. The Plug-ins

Six PCC software plug-ins have been created to address the relevant USAR ground station requirements. The first plug-in is the Engine-Manger that addresses the requirements that apply to small internal combustion engines typically used by the RC community. The Watt-meter plug-in handles many of the same requirements as the Engine-Manager, but does it for electric engines. The TIL-assist plug-in provides special part-time displays for automated take-off and landing maneuvers and provides flight path deviation warnings in-flight. A modified air-speed readout has been created in order to display the information in the exacting specification provided by the USAR. The Range-Plot plug-in monitors and displays the Line-Of-Sight (LOS) and radio communication limitations. The final two software plug-ins, Altimeter-Setting and Side-slip-Angle, provide a full-time display of the current altimeter setting and a display of the side-slip angle. These groupings were conducted with adherence to USAR 1721(c) which requires "appropriate grouping".

Each of the plug-ins, in addition to their specific requirements, must also satisfy all USAR mapped as being "Ubiquitous". The first USAR of interest in this regard is USAR 1732 which mandates that safety critical windows, "must be accessible at the first level of the pull down menus". All of the plug-ins presented here have their primary menu item at the first level of the pull down menu from the main menu bar. Non-safety critical menu items such as settings for each plug-in are not held to this same standard.

The stock PCC's menu bar is in compliance with the requirement. An examination of the right-click menu for

way-points raises some questions. Commanding the aircraft to a way-point that overlaps another way-point, a fairly common occurrence, requires the use of a second level menu item. However, constraining the menu to provide these options at the first level of the menu could result in a menu that is too unwieldy and make it less useful. The standard API does not allow for manipulation of this menu, so this is an issue that CCT will need to address.

As described by USAR 1785 certain colors are required to be used only for specific purposes. The colors red, amber, and green indicate states of warning, caution, and safety respectively. These colors were matched to the corresponding colors used in the PCC.

Although the PCC does have the color amber available most of the status lights only use red and green. This means that even a minor error is displayed as a red warning. The result is that the operator ceases to be alarmed by the red status light because regularly occurring disturbances can cause red to be displayed. The Status lights bar shown in Fig. 1 is a screen-shot of a typical PCC display during flight. The ATT light is displayed in red because the aircraft's turn was two degrees greater than commanded. This is well within the expected behavior of the UAS during flight, but it is displayed at the same severity as the LINK light which is indicating that a complete loss of the command and control link. The difference in the severity of the error is not made apparent through the coloring as intended by USAR 1785.

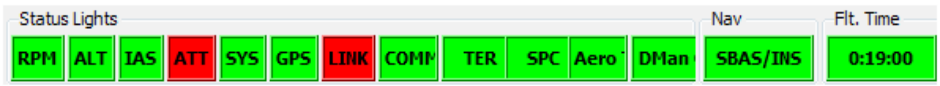

Figure 1. Status Lights during flight. *The status lights show both a minor and major error in red making identification of safety risks more difficult.*

The Piccolo typically reports problems in a Boolean fashion. Either there is a problem or there isn't which corresponds well to a red / green coloring scheme. Including an amber state will require that a layer of intelligence be applied to determine whether the error warrants a warning or a caution. Additionally the status lights bar cannot be removed from the PCC window nor can it be altered by the exposed API for plug-in creation. For these reasons this issue is one that CCT will need to address or make accessible.

Finally, USAR 1727 (3) requires that sensory cues be easily comprehensible. Beyond visual cues, only aural cues are possible without additional hardware. The PCC contains a function whereby the operator can be alerted of the highest-priority issue aurally. Unless this system is disabled there is no assurance to the plug-ins that any audio played will not interfere with the PCC's audio. One must be careful in excessive use of aural alarms as they can interfere with standard operations especially if they sound very often for minor failures or conditions. Due to these complexities none of the plug-ins presented here use audio as a method of conveying information.

IV. Engine Manager

There are several USAR dedicated to the proper monitoring of the power-plant on-board the UAS. This research effort focuses on the smaller UAS that use typical hobby-grade RC type engines. For these types of engines most of the requirements are not-applicable as they do not typically provide feedback to the controlling mechanism. As such the data that is available comes from additional sensors and estimations such as RPM sensors or current sensors for electric motors. Using these engines simplifies the USAR display requirements since many of those requirements are directed toward much larger UAS with turbine engines.

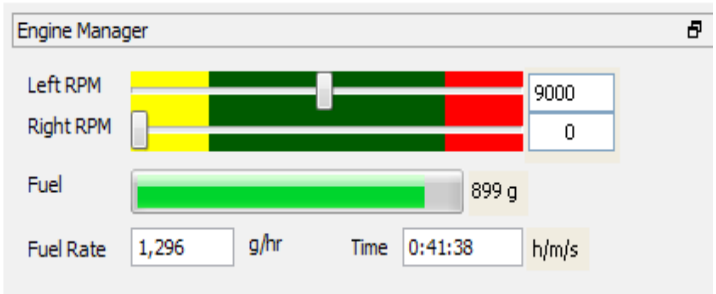

Figure 2. Prototype of the Engine Manager plug-in.

The relative lack of engine feedback data means that what little data that is available is critically important to the operator for maintaining good SA about the UAS propulsion system. The data that is displayed in the Engine Manager plug-in is available as numerical information in various displays scattered around the PCC. The result is that the engine information can be difficult to find and not easily interpreted at a glance as it is available through the standard PCC.

To aid the operator in quickly determining the status of the UAS, engine data are gathered into a single frame and displayed as slide gauges. This allows the operator to know the current RPM and Fuel levels at a mere glance similar to the display on an automobile's dashboard. The fuel burn rate estimation is provided in accordance with USAR and although not required by the USAR the burn rate and fuel remaining data are used to calculate the

amount of time left till fuel exhaustion to help reduce workload on the UAS operator. Figure 2 above shows the Engine Manager plug-in as it would appear during use in the CCT PCC display.

V. Watt-meter

Whereas the Engine-Manager plug-in fulfills the requirements for combustion engines the Watt-Meter plug-in was developed to accommodate electrically powered UAS. This plug-in specifically satisfies the requirements of USAR.U1801 (Battery Discharge Warning).

The Watt-meter is unique in that it is the only plug-in that employs non-standard hardware to supplement the standard Piccolo equipment. A board designed in house is connected to the battery that measures the battery voltage and current draw. This board is then interfaced to the Piccolo through one of the available analog inputs. The plug-in allows for user inputted calibration and battery charge capacity. This allows the plug-in to make much better estimates of the remaining charge of the battery when compared to the Piccolo's estimation.

The Watt-meter plug-in calculates values that are not available elsewhere in the PCC, so numeric readouts are provided. The vertical bar indicates the Watt-Hrs remaining in the battery as shown in Fig. 3. The gauge will change to yellow and red to indicate progressively lower charges (30% remaining for yellow indication, 10% remaining for Red indication). Additionally, USAR 1801's requirement to warn of a continuous power drain malfunction is satisfied by changing the background of the watts field to red when excessive power draw occurs.

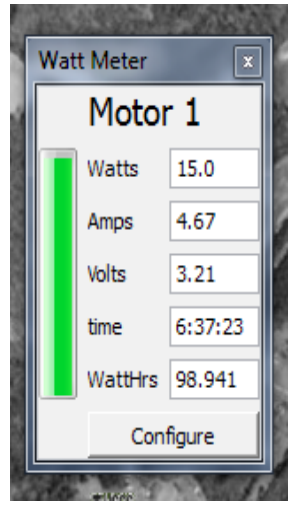

Figure 3. Watt-meter plug-in.

VI. Take-off, In-flight, and Landing (TIL)-Assist

The TIL-Assist plug-in provides information that changes for each phase of flight; **T**ake-off, **I**n-flight, and **L**anding. For each phase there is a corresponding tab. The PCC already tracks the phase of flight and displays it as the "Autopilot Mode" and displays it below the main menu bar. Using this information, the plug-in is able to switch automatically between each mode, as recommended in the STANAG section "Acceptable Means of Compliance (AMC)" AMC.1722(b). The tabs allow the user to view the display of an alternate mode if needed.

For the Take-off phase compliance requires adding a read-out for the deviation of the UAV from the expected approach path. USAR 1730 only mandates the display of the commanded flight path and the deviation from the flight path. To make the plug-in more helpful and improve the safety of the system, two additional values are shown: RPM and Airspeed. These two values are the Piccolo's abort criteria for the launch. Figure 4 shows the TIL Assist plug-in for the Take-off phase.

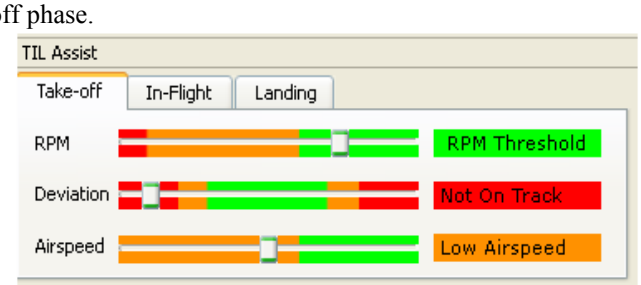

Figure 4. Take-Off Assist *Potential state of the meters showing a UAV whose engine is ready, but is too slow to take-off and has deviated from its commands*

During the In-Flight phase of the mission the plug-in targets the requirement for a mid-flight deviation monitoring capability as specified by USAR 1827. A robust algorithmic solution to this problem is still in development. Until that algorithm is complete the plug-in will use a greatly simplified model where: green is deviation less than threshold, amber is deviation less than turning radius, and red is any deviation greater than the turning radius. This gives the operator some indication of deviation and sounds the alarm if it is clearly out off path. When the Piccolo is not in an automatic mode, as defined in USAR.1329, the indicator will remain grayed out to indicate that it is not active. A meter also displays the current deviation relative to the limits as shown in Fig. 5.

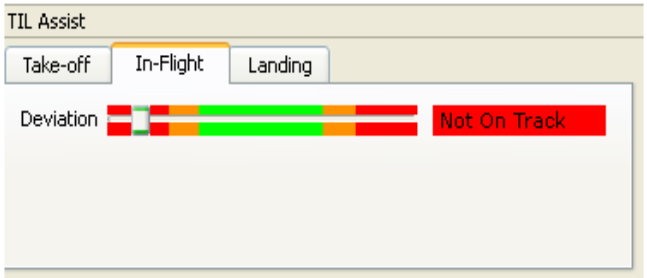

Figure 5. In-Flight Assist *During flight information is minimized*

During the landing phase of flight, the same USAR as take-off applies. Similar to the take-off sequence, more information is included by the plug-in than the minimum requirements. In this case the abort criteria have changed to include altitude and airspeed as shown in Fig. 6.

Figure 6. Landing Assist *Potential state of the meters showing a UAV in good condition to land*

VII. Air-Monitor

The requirements of air monitoring are relevant to all UAS regardless of scale. The PCC has an existing airspeed indicator built into the Primary Flight Display, but it doesn't meet the requirements of the USAR. The exposed API does not allow a user to modify any of the indicators in the Primary Flight Display so the Air Monitor Plug-in was developed to meet those requirements. The color regions along the bar are strictly defined in USAR 1835. The user of this plug-in will define the necessary information in a text file that is loaded at initialization. This data can add a lot to the display as shown in Fig. 7.

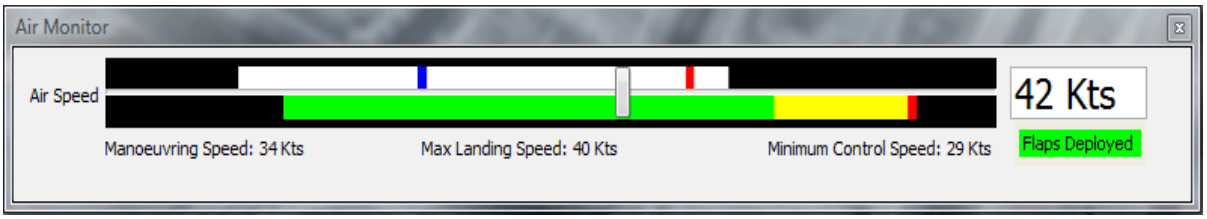

Figure 7. Air Monitor *Most information intensive case shown*

VIII. Range-Plot

This plug-in displays the current position and flight-path against line-of-sight and radio link limitations. The line-of-sight is drawn onto the main map as a red circle centered at the ground station. The range is based on a user inputted value. The radio link limitation is displayed as a blue line on the main map which shows the maximum range of the command and control data link. This distance is user defined as per USAR 1607(a) . The effect of altitude based on this user data is automatically applied to the boundary.

IX. Altimeter Setting

This small plug-in fills USAR 1723(a) criteria 2 by displaying the altimeter setting as a dock-able widget. These data are displayed in the "Pre-flight" window, but the window is considered by this research to be a part-time display due to its function and size. Since the altimeter setting is required to be displayed full-time, a small plug-in

is able to free up significant screen real-estate that would otherwise be occupied the "Pre-flight" window. This plug-in also addresses an issue in the PCC where selecting GPS altitude will overwrite the altimeter setting without telling the operator.

It should be noted that this requirement is a bit of an awkward addition to the PCC because while the altimeter setting is required to be displayed full-time, the Piccolo does not necessarily use the barometric altitude. Using GPS or DGPS, the Piccolo can perform well without ever using the barometric sensor.

X. Side-slip Angle

The PCC calculates most values required by various USAR. However the side-slip angle is not one of those calculated fields. This plug-in fulfills USAR 1723 (b) criteria 2 by providing a display of this value. Because this is such a small addition it could be included in the "Telemetry" window in a future version of the stock PCC.

XI. Conclusions

The mapping methodology used was effective in determining which requirements needed to be addressed in order to achieve compliance with STANAG 4671 section I. These requirements were then compiled into software specifications which could be implemented. The resulting plug-ins together form a suite of tools that operators may employ towards their standardization efforts. Because specific systems may have their own requirements not considered in this research, a thorough review of STANAG 4671 section I for that system should be conducted. Finally, while this research is of greatest utility to users of the Piccolo autopilot, it is believed that the mapping methodology and results will be helpful to those in the process of their own implementation of STANAG 4671.

Appendix A – USAR Mapping

General			
USAR	*Description*	*Mapping*	*Plug-in*
1701	General	Ubiquitous	
1702	UCS infrastructure	Physical Requirements	
1703	UAV crew work place	Physical Requirements	
1704	Minimum UAV crew	Physical Requirements	
1705	UAV crew work place lights	Physical Requirements	
1707	Communication system	Physical Requirements	
1709	Voice recorders	Physical Requirements	
1711	UCS data recorder	Addressed in Base PCC	
1717	UCS electrical systems	Physical Requirements	
1719	UCS power supply	Physical Requirements	
1720	Automated Mission Planning	Scope	
DATA DISPLAYED IN THE UAV CONTROL STATION			
USAR	*Description*	*Mapping*	*Plug-in*
1721	Arrangement and visibility	Mapped	Engine Manager
1722	Part-time data display	Ubiquitous	TIL Assist
1723	Flight and navigation data	Mapped	Air Monitor, Range Plot
1725	Powerplant data	Mapped	Engine Manager
1726	Data display of equipment required by Operations regulation	MSSAC	
1727	Electronic data display	Ubiquitous	
1728	Data link data display, warnings and indicators	Mapped	Range Plot
1729	Fuel quantity and oil quantity data	Mapped	Engine Manager
1730	Automatic take-off system or automatic landing system data	Mapped	TIL Assist
CONTROLS			
USAR	*Description*	*Mapping*	*Plug-in*
1731	General	Ubiquitous	
1732	Safety critical controls	Ubiquitous	
1733	Conventional controls and indicators	Physical Requirements	
1735	Motion and representation of controls	Physical Requirements	
1741	UCS flight controls	Addressed in Base PCC	
1742	Flight termination system control	Piccolo Limitation	
1743	Fuel controls	Piccolo Limitation	
1745	Fuel jettisoning control	Piccolo Limitation	
1747	Air induction control	Piccolo Limitation	
1751	Engine and APU controls	Mapped	Watt-Meter, Engine Manger
1753	Ignition switches	Addressed in Base PCC	
1755	Mixture controls	Piccolo Limitation	
1757	Propeller speed and pitch controls	Piccolo Limitation	
1759	Propeller feathering controls	Piccolo Limitation	
1761	Turbine engine reverse thrust and propeller pitch settings below the flight regime	Piccolo Limitation	
1763	Carburettor air temperature controls	Piccolo Limitation	
1765	Shut-off controls	Addressed in Base PCC	
1769	"Abort" control for automatic take-off system or automatic landing system	Addressed in Base PCC	

INDICATORS AND WARNINGS			
USAR	*Description*	*Mapping*	*Plug-in*
1785	Warning, caution and advisory information colour code	Ubiquitous	
1787	UAV automatic diagnostic and monitoring	Scope	
1788	Degraded modes of operation warning	Physical Requirements	
1789	Low speed warning	Addressed in Base PCC	
1790	UAV mode of control indicator	Addressed in Base PCC	
1791	Wing flaps position indicator	Mapped	Air Monitor
1793	Landing gear position indicator and warning	Piccolo Limitation	
1795	Pressurised compartment indicator	Piccolo Limitation	
1797	Fuel pumps warning	Piccolo Limitation	
1799	Air induction indicator	Piccolo Limitation	
1801	Battery discharge warning	Mapped	Watt-Meter
1803	Indicators for power-assisted valves in the powerplant	Piccolo Limitation	
1805	Shut off valves indicator	Piccolo Limitation	Engine Manager
1809	UAV electrical systems warning and indicator	Mapped	Watt-Meter
1811	De-icer boot system indicator	Piccolo Limitation	
1813	Hydraulic systems indicator	Piccolo Limitation	
1817	Fire protection warning	Piccolo Limitation	
1819	Pitot heat indicator	Piccolo Limitation	
1821	UCS Power distribution indicator	Physical Requirements	
1825	Flight control system lock warning	Piccolo Limitation	
1827	Flightpath deviation warning	Mapped	TIL Assist
1829	UAV safety status indication	Piccolo Limitation	
INFORMATION, MARKINGS AND PLACARDS			
USAR	*Description*	*Mapping*	*Plug-in*
1831	General	Ubiquitous	
1835	Airspeed data	Mapped	Air Monitor
1837	Magnetic heading or track data	Addressed in Base PCC	
1839	Powerplant and auxiliary power unit data	Mapped	Engine Manager
1841	Oil quantity data	Piccolo Limitation	
1843	Fuel quantity data	Mapped	Engine Manager
1845	Control markings	Mapped	Engine Manager
1849	Operating limitations indications	Physical Requirements	
MISCELLANEOUS			
USAR	*Description*	*Mapping*	*Plug-in*
1881	UAV hand over between two UCS	Physical Requirements	
1883	Command and control of multiple UAV	Physical Requirements	
1885	UAV handover within the same UAV control station	Physical Requirements	
1887	Multiple UAV monitoring	Addressed in Base PCC	

References

[1] "STANAG 4671 (Edition 1) – Unmanned Aerial Vehicles Systems Airworthiness Requirements (USAR)," *North Atlantic Treaty Organization Standardization Agreements*, URL: http://www.nato.int/docu/stanag/4671/4671_ed1_e.pdf [cited 03 March 2010].