Cognitive Loading, Affect Regulation and Aerodynamic Considerations in Uninhabited Aerial Vehicle Systems Refueling Operations

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***Abstract*—Factors influencing aerodynamics involved in aerial refueling illustrate the potential for specialist operators to manage these operations for remotely piloted vehicles. The authors review aerodynamic characteristics of uninhabited aerial systems during refueling, drogue and boom design and associated flight dynamics, cognitive factors associated with control transfer and refueling, and affective components and their influence on decision making and operator performance. Attention is directed to cognitive loading and encoding challenges, with considerations for hippocampal mapping and hemispheric asymmetry. Implications for system state awareness are examined. Advantages for specially trained refueling pilot operators are discussed and recommendations given for areas of concentration.**

Keywords—aerodynamics; inflight refueling; cognitive load; and affect regulation, operators.

I. Introduction

With rapid developments in civilian applications for uninhabited aerial systems (UAS), and refinements in the military context, this paper considers a potential trajectory of further enterprises. Overall, the cognitive factors for competent operator performance have been of interest and concern among entities that deploy or intend to operate UAS in various applications. In the same light, design characteristics for a wide range of vehicles have surfaced a number of aerodynamic considerations. The authors believe it is timely to couple aerodynamic challenges for UAS operators with cognitive loads associated with aerial refueling. Clearly, the missions that would require aerial refueling are well known in the military context, however, as UAS are employed in long range or extended endurance roles for civil operations the potential need also arises. The authors review principal aerodynamic considerations for aerial refueling, introduce cognitive load and affective influences, and discuss potential effects as UAS enterprises advance in the workplace.

II. Aerodynamic Considerations

Refueling operations for UAS present various aerodynamic challenges. Among these are matching speed and altitude for refuelers and receivers, maneuvering for boom docking, oscillations with drogue funnel cones, and visibility limitations. Further, as noted by McAndrew (2013), weight and balance issues can be paramount when fuel is on loaded requiring speed and axial modifications. For UAS, this requires substantial operator experience to adjust incrementally to avoid unintended supply line separation. To date, some of the challenges are addressed in design modifications, control protocols, and operator training.

Uninhabited aerial systems employ a wide range of aircraft, propulsion systems, and operational functions. Some of these systems are involved in extended or remote locations where refueling opportunities are scarce or lacking (rescue or firefighting, for example). An alternative is to receive fuel on station or nearby from an orbiting tanker. While inflight refueling has primarily resided in military operations, civilian applications are close behind [1]. In other contexts, these systems and vehicles may require refueling from remote airborne platforms that allow for increased time on station and reduced risk of transiting to a refueling depot or attempted landing in unprepared areas.

The Design Effects and Maneuvering, in an Airframe modifications for UAS vehicles to accommodate aerodynamic effects from aerial refueling have not been a subject of many studies. During aerial refueling, successful docking presents challenges in the presence of tanker wake vortex, horseshoe wing vortex and atmospheric turbulence, particularly relevant with a nonstationary drogue in the tanker flow-field. Drogue designs are passively stabilized aerodynamically and, consequently, can experience large displacement motions in turbulence that is moderate to severe any Air Force. This presents a high demand for cognitive processing by the systems operator to evaluate appropriate responses. As drogue technology and design configurations develop, the aerodynamics involved will become more complex and varied with trajectory tracking devices and feed-forward trajectory set point controllers [2]. UAS operators will need to remain current and proficient with each succeeding development.

Various design configurations of drogues and paradrogues invites consideration of canopy profile effects, flow separation, and steady-state anomalies regarding aerodynamic characteristics. As noted by others [3], a disadvantage of the hose-drogue-probe method is of failing to connect in poor weather conditions or with a damaged aircraft. Similarly, latency in communications represents a difficulty in cognitive cycling where working memory may become taxed, in such cases, the success of refueling will depend on the receiving UAS operator's navigation and cognitive competencies. As frequency of refueling operations increases, having specialists for this operation may be warranted. To achieve this, a transfer of control function would be needed.

A model developed for aerial refueling model for maneuvering [4]. This is helpful in assessing refueling scenarios and unforeseen situations that the typical operator is not trained to address. Of concern are the discrete dynamics (which occur during flight transition maneuvers), and the continuous dynamics represented by evolution of aircraft states during individual maneuvers (Northup Grumman, 2013). Where specially trained operators are used, they would be familiar with the capture and collision sets based on the Hamilton-Jacobi reachability method [5]. These sets would be used for maneuver control laws and switching conditions to satisfy various safety objectives where tanker velocity might vary.

In the detailed analysis of design and aircraft maneuvering issues during refueling with UAS, it identified six flight transition maneuvers, six stationary modes, four general purpose escape maneuvers, and three maneuver sequence problems, as shown in Table 1.

Table 1
Design and Aircraft Maneuvering Issues During UAS Refueling

Flight Transition maneuvers
Determine target-attainability and capture/collision set
Command direction by either the human operator or preprogrammed scenario
Banking left or right
Speeding up to join tanker
Slowing aircraft upon detachment from boom
Avoiding excessively conservative decisions
Stationary Modes
Awaiting command for next transition maneuver
Stabilizing controls
Guarding against unsafe commands
Considering feasibilities regarding delayed information
Assessing effects of latency on visual capture sets
Assuming no change in altitude for the aircraft
General Purpose Escape Maneuvers
Steering left maximum speed
Steering right maximum speed
Slowing down
Speed up
Maneuver Sequence Problems
Ordering of maneuvers not preprogrammed
Time horizon must not be exceeded
Composition of sequence through switching conditions

Note. Adapted from "Reachability Calculations for Vehicle Safety During Manned/Unmanned Vehicle Interaction," by J. Ding, J. Sprinkle, C. Tomlin, S. Sastry, and J. Paunicka, 2012, *Journal of Guidance, Control, and Dynamics*, 35.

These 19 maneuvers all have the potential of occurring during aerial refueling. Further, as point out, the maneuvers are exacerbated by communication latency, adverse weather, aircraft model, unstable atmospheric conditions, hybrid designs, and variations in feedback control. To expect that an operator who has just transitioned from the enroute phase, multiple flight control authorization exchanges, and the initial refueling engagement scenario is cognizant and fully capable of memory retrieval of information related to one or more of the hundred-plus possibilities, could reasonably be seen as extraordinary. While such operators are available, one could presume they are not in great abundance. On the other hand, an operator who is well versed in these scenarios and has a mental focus congruent with the tasks to perform may be able to accomplish the refueling with less risk of not succeeding. Further, when the refueling is completed, transfer to a different operator who has not been heavily tasked with the refueling operations might allow that fresh operator to more readily process the next task sets with reduced deficit.

It was noted that aerial refueling tests for UAS have been in smooth air, minimal turbulence, and in straight and level flight at constant airspeed [6]. This suggests that in less than optimal conditions, more reliable control may be performed by experienced operators familiar with aerodynamic variations among the tankers being used. In this regard, the suggestion of control transfer has been described previously [7] Advantages noted included influences from Dutch Roll caused by wake effects, reduced need for yaw control, and accommodations from propeller wash, if present. Similar influences have been when investigating probe-drogue and boom-receptacle configurations for UAS refueling where receiver aircraft dynamics were characterized as complex, nonlinear, and with cross-coupling issues identified as a challenge [8]. These factors and considerations, when taken together, suggest there may be an advantage in using specialists for refueling operations. Since refueling specialists could be located in nearly any ground control station, control transfers would be sufficiently practiced and anticipated in flight planning.

Cognitive Load can be several conditions aligned with aerodynamic factors can materially influence cognitive loading for operators including turbulence and displacement motions, maintaining currency, keeping abreast of new design configurations, issues with open-loop processing, aerodynamic variations among tankers, and increasingly sophisticated navigational and positional systems. Associated with these conditions are related cognitive tasks which occur during phases of aerodynamic maneuvering which influence cognitive loading.

The concept of cognitive loading was introduced in 1988 and explicated in 1990 [9]. Cognitive load describes the amount of mental effort expended for working memory. As the term came into use for aviation applications, references to information processing became prominent with particular emphasis on perception, memory, and reasoning [10]. It was noted [11] that when examining UAS and human factors, cognitive load is among the three principal metrics to determine human performance. These researchers found that achieving an optimal level of cognitive performance would be interconnected with sustained situational awareness and dissipation of complacency effects.

As the field of neuroergonomics grows [12], the issues and concerns raised in the UAS aerial refueling discussion are naturally integrated. As noted earlier, particular research on mental workload, and especially overload, have focused on situation awareness, information processing, and decision making where they are simultaneously present. When too high or too low, cognitive load increases risk of error, more notably when abrupt bursts of a large amount of information must be processed quickly [13]. This would likely occur, for instance, during challenging inflight refueling attempts.

Among perceptual tasks during refueling is constructing a cognitive map of the environment and interacting influences. Recent findings [14] showed he working environment for a UAS operator comprises, in many respects, a virtual environment. The hippocampus is recruited when a person develops a cognitive map of the environment, including calculation of distances and space, and is further mediated through the post rhinal and entorhinal cortex. In virtual environments, results showed that as much as half the hippocampal neurons usually involved were actually shut down and the cognitive map was nonexistent. The researchers are continuing their investigation to more accurately identify which neural components are operating in place of the hippocampal neurons, and brain rhythmicity is the current leading candidate for investigation. The implications for UAV operators are profound. This suggests a different region of the brain is involved in the spatial learning tasks and processes, compared with on-board pilots, and is complicated when perceptual variances become intertwined (one using virtual cues and the other real-world cues).

Operators of UAS are embedded with virtual environments, in addition to real-time imagery. As tasks concatenate, cognitive resources become depleted [15]. Recent evidence indicates that very different brain processes are involved in comprehending meaning from these sources. Focusing on one dimension of this phenomenon studied hippocampal cognitive maps and found they appear to be actuated by distal visual and self-motion cues [16]. However, theta frequency was reduced and, although temporal coding was less affected, the researchers suggest there appears to be a competition among sensory cue interactions with regard to hippocampal spatiotemporal selectivity and theta rhythm. They also found that, unlike real world position encoding, bidirectional cells were predominant in encoding in the virtual environment.

Earlier it was described how UAS can have limited field of view, and that vision out of the sensor suite is confined and narrow (typically limited to around 45 degrees of look-angle or slant range) [17]. This can seriously degrade situational awareness and resultant cognitive mapping. When employed with UAS, limited views have the potential to invite channelized attention, confirmation bias, and loss of energy state awareness) [18]. Experienced UAS operators would have a notable advantage during refueling operations since their cognitive map would be oriented to potential variant views situationally.

Only recently are neural sensors and passive measures for brain wave activity entering the UAS operator literature. One of the groundbreaking studies outside of the laboratory [19] revealed that all of the EEG frequency bands responded to cognitive activities during flight, especially during high workload activities like takeoff, landing, and reduced visibility conditions. Such increased and sustained activity would clearly result in a more rapid consumption rate of available brain glucose necessary for effective functioning, advancing the onset of the refractory period during which restoration of energy would occur. This could conceivably be at or near the point where termination of inflight refueling takes place and the operator must transition into a new environment and task sequence.

In examining electroencephalographic mapping of cortical activation, identified links in the anterior cingulate gyrus with sustained attention, conflict resolution, and rapid updating of working memory [20]. This further confirmed that as mental processing of multiple subtasks increases, the attention resources become strained. Researchers built on this work and found frontal theta oscillations were associated with changes that produced high workload and a corresponding need for rapid adaptation [21]. More surprisingly, though, their results showed that temporal gamma oscillations demonstrated a strikingly different pattern associated with moving between tasks. The results suggest that early detection of performance degradation is not likely if just observing frontal theta. However, as the number of tasks increases there appears to be a relationship with temporal theta that would indicate post-workload transition effects might manifest with onset of a high level of workload. This is precisely the situation when the enroute UAV operator must transition to the refueling task.

Aircraft handoff issues for workload transition and adaptive automation were studied. The researchers found that the nature of a non-linear task environment, like that found with adaptive automation, stimulated operator concerns about future states of the system (e.g., performing look-ahead and what-if analysis). Operators can become disoriented or confused when levels of automation shift in the operating protocols or algorithms. These are demonstrated in operator states involving fatigue, low brain glucose levels, orthostatic hypotension and resulting reduced blood-brain supply, visual disparity, spatial disorientation, and degraded communication [22]. UAS operators entering into aerial refueling, especially with multiple adaptive tasks involved, would almost certainly benefit with an absence of such performance degrading states.

During typical UAS flights, there are several handoffs to different controllers as vehicles transit maneuvering areas, mission parameters, air traffic control zones, and international boundaries. To accomplish increasingly complex handoffs, UAS are becoming more sophisticated with distributed electronic systems. Likewise, there has been an increase in the number of parties involved and the number of interactions between operators, controllers, coordinators and others in a distributed information network. When describing 12 states attributed to a flying object, [23] discussed problems with distributed control and data. Among the issues identified were data inconsistencies due to transmission delays and inconsistencies from data packet loss. The researchers also found differences among operators regarding visual perception and information extraction. Such effects add to cognitive loading and working memory processing. UAS operators with extensive experience in refueling operations can anticipate some of these inconsistencies and have an outline mental schema for reducing unwanted interference.

Recently, hysteresis increasingly is being investigated in vigilance monitoring to determine the effect of shifting event rates [24]. In this context, hysteresis applies to the history of previously experienced events and their influence on current operator levels of mental workload demand. Findings indicate that operator expectancy is maintained for some time after a switch to lower task workload conditions. This results in an overall reduction in subjective workload capacity for the operator. Where operator control transfer were to occur after inflight refueling, this performance decrement might be avoided.

It was recognized the importance of cortical hemodynamic effects during workload transition [25]. In particular, they noted effects that increase cognitive load and where there is not sufficient temporal resolution to accommodate transient events. This has been further investigated who note that during periods of prolonged, steady-state, low to moderate workloads (as in cruise and enroute segments) there can be transitions into relatively brief events with high workload (as in aerial refueling) [26]. When addressing differences between single and multiple operator to vehicle ratios, it was observed that increasing attempts to reduce UAS staffing have moved toward single operators overseeing multiple UAS architectures in a network, requiring significant operator cognitive resources.

Attempts to reduce workload for UAS operators is an ongoing subject of research. Earlier, the distinction between workload management and attention management was identified [27] relating to prospective memory and neglect of essential tasks because of excessive workload. As noted, deferring an action can lead to displacing the trigger cues needed to retrieve the action from an associated procedural flow. As UAS operators become loaded near maximum during especially challenging rendezvous and docking procedures, displacement such as this could be catastrophic.

Drawing upon the model developed for working memory, and including recent findings for bandwidth issues and protein cycling limits [28], it becomes readily apparent that UAS operators during refueling operations can reach saturation of working memory buffering. Among the factors influencing memory loading is maneuvering to the tanker rendezvous point [29]. The ATC interface typically requires updating GCP waypoints and maneuvering accordingly the researchers concluded that too much stimulation or too little stimulation can conflict with coding new memory. For UAS operators already encoding large amounts of information, an opportunity to reduce the concentrated procedures for inflight refueling may offer some respite [30].

An issue identified early in the emergence of UAS has been that of communication lag between ATC, Ground Control Stations (GCS), coordination, operators, and others. The information transit time is typically from 7 to 30 seconds, during which operators may be involved in decisions or monitoring to understand effects. This was highlighted in a summary perspective [31] that discussed the delta gap, shown in Figure 3, resulting from these multiple communication links. The effect is further exacerbated as the number of vehicles per operator or supervisor increases, causing the gap in communications to increase.

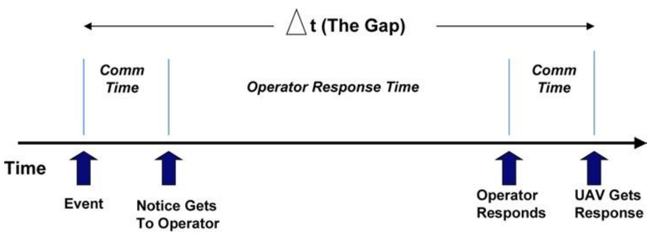

Figure 3. Schematic of decision time span, known as “the gap,” for UAS operator during refueling operation. Adapted from “Unmanned Aerial Vehicles: Autonomous Control Challenges, a Researcher’s Perspective,” by B. Clough, 2005, *Journal of Aerospace Computing, Information, and Communication*, 2, p. 338.

With cognitive shifts from closed loop to open loop processing, the operator is likely to be cycling two or more scenarios in working memory, with rehearsal and encoding challenges continually involved to comprehend vehicle maneuvers and intended docking processes. To retrieve these from long-term memory suggests a relatively clear channel would be requisite for effective cognitive operations. Related to this is the issue of working memory involved with primary and secondary tasks competing for brain bandwidth and cortical resources. This likelihood becomes pronounced with one operator controlling multiple vehicles. Where level of automation is not a significant factor [32], what has become evident is that although mental resources are not always completely expended for primary tasks, the presence of competing demands from secondary task components can strain the primary functions to the point of saturation.

III. SITUATIONAL AWARENESS

Another approach to reducing operator involvement and associated cognitive loads has been to introduce special purpose sensors, cameras, and software. Others identified thirteen variables (e.g., angular velocities, kinematic angles, deflections, and dimensional forces) influencing trim of the boom alone [33]. Issues of open-loop control arise here, and may detract from effective control transfer. Alternatively, where specialists would engage the docking and continue through the refueling process, continuity and closed-loop conditions might be preferable.

A focus on human factors design issues was developed to task analysis of UAS operations. The researchers identified concerns with data-delay links, control design, cognitive workload, displayed information, situation awareness, target detection, and design for training and teaming. When examining just one of the concerns, cognitive workload, the researchers identified five particular factors (Table 2) that would affect vigilance.

Table 2
Factors Affecting Vigilance

1.	Number of flight parameters controlled by a single operator,
2.	Degree of operator involvement in obstruction and threat avoidance,
3.	Number of UAS controlled by a single operator,
4.	Difficulty of target search and recognition, and
5.	Difficulty of situation assessment.

Note. Adapted from “Human-Centered Design of Unmanned Aerial Vehicles,” 2003, M. Moulala, R. Gilson, and P. Hancock, Winter, 6-11.

At that time, the researchers also raised the issue of particular combinations and degrees of load factors and cognitive resources of operators. Familiarity with these five factors, and strategies for successfully negotiating each as they arise, could be an integral aspect of specialized training for UAS refueling specialists.

Efforts to develop variable decision algorithms for control systems were recently evaluated in their study which coupled a computer with a human operator to evaluate task performance by linking cognitive state sensors, adaptation strategies, and control systems [34]. Results showed a serious problem where a threshold would be exceeded, an adaptive response triggered, and stimuli being pushed back below the threshold in a very short time. In these closed-loop environments, the workload on the human operator was increased profoundly. Operators accustomed to this cognitive state during aerial refueling could, perhaps, be better situated to accomplish the tasks consistent with safe practices.

A line of inquiry into psychophysiology and adaptive automation that included questions about situational awareness was started [35]. Coupled with this is a need to evaluate the efficacy of Endsley's concepts in the UAS environment. While addressing criticisms of this model [36], describes situational awareness (SA) as a working memory bottleneck for operators in novel situations. For more experienced operators with skilled performance capabilities, increased recruitment of long term memory augments the SA process and results in fewer gaps or performance decrement. Operators of this caliber create heuristics and work cues to assist them in keeping up with their task status. Consequently, the volume of mental processing to sustain high levels of SA require operator access to embedded mental constructs in long term memory. Given these conditions, specialists with expertise in UAS aerial refueling would be included in the experienced and practiced operator category.

IV. AFTER REGULATIONS

The affective component is often associated with cognitive processing. It has been noted [37] that operators on the refueling platform may be compromised by fatigue and oscillation effects. While operators at a distant ground control station may not have the same kinesthetic and proprioceptive experiences, they are, still, affected by tension, anxiety, fatigue, and a host of other factors. All of these conditions may influence affect.

Operators of UAS often are working with multiple screens and monitors. As would be expected, the visual component of perception is subject to saturation from stimuli and data. Accompanying visual input is the need to interpret the significance or urgency of the information [38]. Perceiving what is critical, what is evolving, and sequences for actions becomes paramount. For instance, it was noted that roles and motives of remotely piloted vehicle operators differ in matters of visual perception, lack of sensory assimilation, increased signal noise, and information extraction. When the affective domain is considered, under heightened stress the range of cues extracted can narrow spatially and temporally [39]. Operators who specialize in particular aspects of aerial refueling would likely experience fewer of the stresses accompanying inflight refueling operations compared with operators primarily who handle enroute and mission tasks.

A resulting uncertainty with regard to conflict resolution can occur between two states such as enroute and aerial refueling procedures. Conditions such as visibility limitations or turbulent weather can contribute to operator uncertainty. Similarly, turbulent conditions can increase the time to assess and enter data resulting from unstable sensor and instrument readouts and aircraft attitude variations. While cognitive memory is generally mediated in the anterior hippocampi, affective memory is processed via the amygdalae. Often, amygdala-driven memories can take precedence in neural sequencing. For some operators, amygdala-level situational appraisal may invite distorted pattern recognition and proneness to false alarms [40].

Hemispheric asymmetry is well established and has implications for UAS operators with right side dominance. Others [41] found that differences between high and low vagal tone levels are related to differences in the evoked response potentials and latencies. Results from their studies indicate a pronounced effect for differences between the vagal tone conditions on various stages of information-processing. Operators with lower vagal tone can be prone to becoming anxious when attempting refueling, if they have experienced unsuccessful or problematic docking in the past. A corollary to this condition may be increased right prefrontal cortex involvement and resulting uncertainty at critical junctures. Some of the obvious implications are in screening and identification of operators who may present with these tendencies.

The concept of system state awareness compares what an individual experiences as awareness with what is actually the system state [42]. In a distributed cognitive network, where what is true of the system according to the mind of the UAS operator may not compare favorably with the metacognitive mapping of the actual system operations, this is particular applicable. Consequently, where equilibrium of a system may be anticipated by a UAS operator in a refueling situation, the overall environment may not be aligned correspondingly. Acting or responding within this incongruity could result in potentially hazardous consequences. Predispositions, and corresponding attitudes, could conceivably play a major role in conflict resolution strategies for UAS operators. Specialists in refueling operations would be well aware of their values in this regard and would have concentrated practice in recognizing and resolving the attendant conflicts.

When varying altitudes are proposed for inflight refueling, in unfavorable weather, dynamic characteristics can present cognitive mindset variations and transition considerations [43]. Even high-time UAS operators can perform marginally when fatigued, when they are less familiar with docking conditions, and with aerodynamic influences during the refueling process. Degraded situational awareness can be a factor. This can be critical when lower ceilings require lower altitude refueling operations or refueling in cloud cover. Emotional states may be heightened during such events. There can be long-term effects that result from continued high-stress working environments, like aerial refueling, where an excess of cortisol destroys hippocampal cells critical in memory storage and retrieval [44].

V. SPECILIZED OPORATORS

While the current environment is expanding rapidly with development of UAS for commercial purposes, eventually the inevitable sorting of enterprises will occur. There may be companies or organizations that would specialize in various UAS support functions like refueling operations. Since distance from aircraft is less of an issue for control station locations, specialist operations might be centralized anywhere in the world. As proliferation of UAS continues, and civil applications become more evident, there are concerns raised about air traffic control, liability, privacy, homeland security, and a host of other issues [45]. It appears reasonable to consider just how far the commercial enterprise will expand, and how far support and production efforts may extend [46]. Specialized operators would materially enhance safety and performance of UAS during refueling operations during such an expansion [47]. It may well be the case that some of the challenges materialize into larger obstacles that may truncate the UAS enterprise [48]. Trusting that is less likely, more research is indicated to determine particular aspects of cognitive loading and affective considerations. The ramifications in operator selection and training are profound [49]. Where neuro-based measures can be incorporated in training, evaluators can identify those operator candidates more suited to specialized task constellations and affinities for related performance skills.

VI. SUMMARY

This review has touched on areas within aerodynamic design, cognitive load, and psychological affect encountered during UAS aerial refueling operations and a proposition advanced that aerial refueling specialists may be advisable to assure greater margins of safety, promote higher performance levels, and avoid or reduce the likelihood of undesirable consequences. These advantages are summarized in Table 3.

Table 3

Benefits of Employing Specialized UAS Operators for Aerial Refueling

Enhancements and Advantages

- Improved capability to meet increases in refueling frequency as industry grows
- Currency and proficiency with airframe and aircraft dynamics
- Timely updates for modifications to drogues, baskets, and boom technology
- Enhanced UAS operator navigation skills when anomalies occur
- Well practiced capture and collision sets and knowledge of manoeuvring laws
- Detailed knowledge of tanker velocity shifts and aerodynamic variations
- Familiarity with 19 transition manoeuvres identified during refueling operations
- Enhanced situation awareness, information processing, decision making
- Well rehearsed cognitive map of refueling scenarios, and associated brain development
- Anticipated sensory cues and field of view characteristics
- Conservation of eeg bandwidth during high workload activities
- Anticipate communication delays and inconsistencies
- Continuity of closed loop processing during autonomous docking procedures
- Enhanced vigilance as a result of familiarity with workload factors
- Sustained high levels of situational awareness and access to embedded mental constructs

Minimizations

- Reduced control transfer issues
- Reduced cognitive load and performance deficit
- Reduced misalignment of system state awareness
- Avoiding hysteresis and reduced workload capacity following switch from high levels
- Reduced incidence of saturated working memory and buffering limitations
- Reduced likelihood of missed essential tasks due to excessive workload
- Reduced stressor effects and fewer cues lost or misinterpreted
- Less complication from inappropriate vagal tone (anxiety), when screened accordingly

Each of the benefits shown has many contributing considerations and could be viewed in several contexts. Overall, though, the factors involved are worthy of continued study and will take a position of greater interest as the enterprise of UAS continues to expand.

REFERENCES

[1] Sundar, K. & Rathinam, S. (2014). Algorithms for routing an unmanned aerial vehicle in the presence of refueling depots. IEEE Transactions on Automation Science and Engineering, 11(1), 287–294

[2] Tandale, M., Bowers, R., & Valasek, J. (2006). Trajectory tracking controller for vision-based probe and drogue autonomous aerial refueling. Journal of Guidance, Control, and Dynamics, 29(4)

[3] Ro, K, Basara, E., & Kamman, J. (2007). Aerodynamic characteristics of paradrogue assembly in an aerial refueling system. Journal of Aircraft, 44(3), 963-970.

[4] Ding, J., Sprinkle, J., Tomlin, C., Sastry, S., & Oaunicka, J. (2012). Reachability calculations for vehicle safety during manned/unmanned vehicle interaction. Journal of Guidance, Control, and Dynamics, 35(1), 138 - 152. doi: 10.2514/1.53706

[5] Mitchell, I., Bayen, A., & Tomlin, C. (2005). A time-dependent Hamilton-Jacobi formulation of reachable sets for continuous dynamic games. IEEE Transactions on Automatic Control, 50(7), 947-957. doi:10.1109/TAC.2005.851439

[6] Gertler, J. (2012). U.S. unmanned aerial systems. Report 7-5700, R42136. Congressional Research Service, Washington, D.C.

[7] McAndrew, I. & Moran, K. (2013, August). Aerodynamic design considerations for in-flightrefueling of unmanned vehicles. Applied doi:10.4028/www.scientific.net/AMM.390.43

[8] Panday, A., & Pedro, J. (2013). An overview of aerial refueling control systems applied to UAVs. Paper presented at the AFRICON Conference, Pointe-Aux Piments, Mauritius, September 2013, 1-5. doi:10.1109/AFRCON.2013.6757788

[9] Chandler, P. & Sweller, J. (1991). Cognitive load theory and the format of instruction. Cognition and Instruction,8(4),293–332. doi:10.1207/s1532690xci0804_2

[10] Antonenko, P., Paas, F., Grabner, R., & van Gog, T. (2010). Using electroencephalography to measure cognitive load. Educational Psychology Review, 22(4), 425-438. doi:10.1007/s10648-010-9130-y

[11] Stark, B., Coopsman, C., & YanqQuan, C. (2012, August). A framework for analyzing human factors in unmanned aerial systems. 5th International Symposium on Resilient Control Systems, 14-16, Salt Lake City, UT. doi: 10.1109/ISRCS.2012.6309286

[12] Parasuraman, R., & Rizzo, M. (2008). Neuroergonomics: The brain at work. New York: Oxford University Press.

[13] Huttunen, K., Keränen, H., Väyrynen, E., Pääkkönen, R., & Leino, T. (2011). Effect of cognitive load on speech prosody in aviation: Evidence from military simulator flights. Applied Ergonomics, 42(2), 348-357. doi:10.1016/j.apergo.2010.08.005

[14] Aghajan, Z., Acharya, L., Moore, J., Cushman, J., Vuong, C., & Mehta, M. (2014, November)Impaired spatial selectivity and intact phase precession in two-dimensional virtual reality. Nature Neuroscience. doi:10.1038/nn.3884

[15] Ungar, N. (2008). Effects of transitions in task-demand on vigilance performance and stress. Unpublished doctoral dissertation, University of Cincinnati, Cincinnati, OH.

[16] Ravassard, P., Kees, A., Willers, B., Ho, D., Aharoni, D., Cushman, J., Aghajan, Z., & Mehta, M. (2013). Multisensory control of hippocampal spatiotemporal selectivity. Science, 340(6138), 1342-1346. doi: 10.1126/science.1232655

[17] Mustin, J. (2002). Future employment of unmanned aerial vehicles. Air and Space Power Journal, 16(2) 86 – 97.National Safety Transportation Board. (2006). Accident investigations. Reports. Retrieved from http://www.ntsb.gov/investigations/fulltext/aab0702.htmlNorthrop Grumman. (2013). Capabilities. X-47B UCAS. Retrieved from http://www.northropgrumman.com/Capabilities/X47BUCAS/Pages/default.aspx

[18] Dodd, S., Lancaster, J., Miranda, A., Grothe, S., DeMers, B., & Rogers, B. (2014, October).Touch screens on the flight deck: The impact of touch target size, spacing, touch technology and turbulence on pilot performance. Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 6-10, Chicago.

[19] Dussault, C., Jouanin, J. & Guezennec, C. EEG and ecg changes during selected flight sequences. Aviation, Space, and Environmental Medicine, 75(10), 889-895.

[20] Gevins, A. (1998). The future of electroencephalography in assessing neurocognitiv functioning. Electroencephalography and Clinical Neurophysiology, 106(2), 165-172. doi:10.1016/S0013-4694(97)00120-X

[21] Bowers, M., Christensen, J., & Eggemeier, F. (2014, October). The effects of workload transitions in a multitasking environment. Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 220-228, Chicago.

[22] U.S. Air Force. (2005). Unmanned air vehicles: A new age in human factors evaluations. Washington, DC: Government Printing Office.

[23] Ali, Q., Gageik, N., & Montenegro, S. (2014). A review on distributed control of cooperating mini UAVs. International Journal of Artificial Intelligence and Applications, 5(4), 1-13.

[24] Mouloua, M., Gilson, R., & Hancock, P. (2003). Human-centered design of unmanned aerial vehicles. Ergonomics in Design: The Quarterly of Human Factors Applications, 11(6) 6–11.

[25] Huey, B., & Wickens, C. (1993). Workload transition: Implications for individual and team performance. Washington, DC: The National Academies Press.

[26] McKenrick, R, Ayaz, H., Olmstead, R., & Purasuraman, R. (2014). Enhancing dual-task performance with verbal and spatial working memory training: Continuous monitoring of cerebral hemodynamics with NIRS, NeuroImage, 85(3), 1014-1026.

[27] Dismukes, R., Loukopoulos, I., & Jobe, K. (2001). The challenges of managing concurrent and deferred tasks. In R. Jensen (Ed.), Proceedings of the 11th International Symposium on Aviation Psychology. Columbus, OH: Ohio State University.

[28] Cottrell, J., Levenson, J., Kim, S., Gibson, H., Richardson, K., Sivula, M., Li, B., Ashford, C.,

[29] Rorie, R. & Fern, L. (2014, October). UAS measured response: The effect of GCS control mode interfaces on pilot ability to comply with atc clearances. Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 64-68, Chicago.

[30] Arden, J. & Linford, L. (2009). Brain-based therapy. Hoboken, NJ: Wiley.

[31] Clough, B. (2005). Unmanned aerial vehicles: Autonomous control challenges, a researcher's

perspective. Journal of Aerospace Computing, Information, and Communication, 2, 327-347.

[32] Liu, D., Wasson, R., & Vincenzi, D. (2009. Effects of system automation managementstrategies and multi-mission operator-to-vehicle ratio on operator performance in UAV systems. Journal of Intelligent Robot Systems, 54, 795-810. doi: 10.1007/s10846-008-9288-4

[33] Doebbler, J., Spaeth, T., Valasek, J., Monda, M., & Schaub, H. (2007). Boom and receptacle autonomous air refueling using visual snake optical sensor. Journal of Guidance, Control, and Dynamics, 30(6), 1753–1769. doi:10.2514/1.28305

[34] Stanney, K., Schmorrow, D., Johnston, M., Fuchs, S., Jones, D., Hale, K., Ahmad, A., & Young, P. (2009). Augmented cognition: An overview. Reviews of Human Factors and Ergonomics, 5(1), 195-224.

[35] Byrne, E. & Parasuraman, R. (1996). Psychophysiology and adaptive automation. Biological Psychology, 42(3), 249-268. doi:10.1016/0301-0511(95)05161-9

[36] Endsley, M. (2015). Situation awareness misconceptions and misunderstandings. Journal of Cognitive Engineering and Decision Making, 9(1), 4-32. doi:10.1177/1555343415572631

[37] Oron-Gilad, T., Chen, J., & Hancok, P. (2006). Remotely operated vehicles (rovs) from the

top-down and the bottom-up. In Human Factors of Remotely Piloted Vehicles: Advancesin Human Performance and Cognitive Engineering Research, 7, 37-47. ISSN:

1479-3601/doi:10.1016/S1479-3601(05)07003-7

[38] Drury, J., Richer, J., Rackliffe, N., & Goodrick, M. (2006). Comparing situation awareness for two unmanned aerial vehicle human interface approaches. Mission Oriented Investigation and Experimentation Project 03057531 of Contract 19628-94-C0001, Case Number 06-0692, MITRE.

[39] Hancock, P. & Weaver, J. (2005). Temporal distortions under extreme stress. Theoretical Issues in Ergonomic Science, 6(2), 193-211.

[40] Arden, J. (2010). Rewire your brain: Think your way to a better life. Hoboken, NJ: Wiley.

[41] Dufey, M, Hurtado, E., Fernandez, A., Manes, F., & Ibanez, A. (2011). Exploring the relationship between vagal tone and event-related potentials in response to an affective picture task. Social Neuroscience, 6(1), 48-62. doi:10.1080/17470911003691402

[42] Kasdaglis, N., Newton, O., & Lakhmani. (2014, October). System state awareness: A human-centered design approach to awareness in a complex world. Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting, 305-309. doi:10.1177/1541931214581063

[43] Cummings, M. (2013). Operator interaction with centralized versus decentralized UA architectures. Collected papers. Retrieved from:

http://web.mit.edu/aeroastro/labs/halab/papers/UAV_ARCH_2013.pdf

[44] Baddeley, A.D. (2007). Working memory, thought and action. Oxford: Oxford University Press.

[45] Heindl, K., Babcock, R., Rose, D., Hempel, C., Wiig, K., Laeng, P., Levin, M., Ryan, T., & Gerber, D. (2013). Working memory impairment in calcineurin knock-out mice is associated with alterations in synaptic vesicle cycling and disruption of high-frequency synaptic and network activity in prefrontal cortex. Science, 33(27) 10938-10949.

[46] Dismukes, R., Loukopoulos, l., & Jobe, K. (2001). The challenges of managing concurrent and deferred tasks. In R. Jensen (Ed.), Proceedings of the 11th International Symposium on

Aviation Psychology. Columbus, OH: Ohio State University.

[47] Endsley, M. (2015). Situation awareness misconceptions and misunderstandings. Journal of Cognitive Engineering and Decision Making, 9(1), 4-32. doi:10.1177/1555343415572631

[48] McAndrew, I. (2013). Design considerations and requirements for in-flight refueling of unmanned vehicles. Journal of Aeronautical Aerospace Engineering, 2:108

[49] Stanford Law School and global justice clinic at NYU School of Law. (2012, September). Living Under Drones. Retrieved from http://www.livingunderdrones.org/wp-content/uploads/2013/10/Stanford-NYU-Living-Under-Drones.pdf