INTEGRATING UAS OPERATIONS IN CLASS C AIRSPACE

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The Federal Aviation Administration (FAA) is investigating Unmanned Aircraft Systems (UAS) operations in the National Airspace System because military, commercial, and civil users want to fly UAS for a broad range of purposes. Our research addresses the potential impact to Air Traffic Control Specialists (ATCS) due to UAS pilots' inability to comply with FAA regulations and air traffic control clearances and instructions that require direct visual means. UAS pilots cannot maintain visual separation from other aircraft, report aircraft *in sight*, or conduct visual approaches. The inability of UAS pilots to rely on visual means may affect ATCS workload, performance, and airspace efficiency. Twelve ATCS participated in teams of two in a high-fidelity, human-in-the-loop simulation. The participants controlled simulated traffic in two complex Class C airspace sectors under three conditions: Manned aircraft only, Low UAS activity, and High UAS activity. We collected measures of airspace efficiency, radio communications, and workload.

The safe and efficient integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) is a primary goal for the Federal Aviation Administration (FAA) as well as UAS manufacturers and operators. UAS operations have increased in both the public and private sectors and the eventual goal is to enable UAS to fly routinely in the NAS as manned aircraft currently do. To achieve this goal, Air Traffic Control Specialists (ATCS) must be able to safely separate UAS from manned aircraft during all phases of flight. However, according to FAA Notice N8900.207, *Unmanned Aircraft Systems Operational Approval*, UAS are not compliant with sections of Title 14 of the Code of Federal Regulations (14 CFR) that pertain to aircraft (FAA, 2013). For instance, the see and avoid provisions of 14 CFR part 91, § 91.113b (FAA, 2014) cannot be satisfied by UAS operators due to the absence of an onboard pilot. For ATC operations requiring visual means of maintaining inflight separation, the lack of an onboard pilot does not permit ATCS to issue all standard clearances and instructions. Consequently, to ensure an equivalent level of safety, UAS operations require an alternative method of compliance or procedural risk mitigation to address the see and avoid limitations. In the future, a permanent and consistent method of visual compliance is needed for UAS operations in the NAS without the need for waivers or exemptions (FAA, 2013).

The research presented here addresses the potential impact on the NAS due to the inability of UAS pilots to comply with regulations and ATCS clearances and instructions that require the use of direct visual observation. Without the use of direct visual observation, UAS pilots cannot see and avoid other aircraft, maintain visual separation from other aircraft, or execute visual approaches. These limitations have the potential to increase ATCS workload and communications and decrease airspace efficiency. We conducted a series of experiments to examine the integration of UAS operations in complex Class C airspace that contained commercial and general aviation Instrument Flight Rules (IFR) controlled traffic and Visual Flight Rules (VFR) uncontrolled traffic (Truitt, Zingale, & Konkel, 2015). The experiment presented here examined UAS integration in a busy Terminal Radar Approach Control (TRACON) arrival stream to Oakland International Airport (OAK).

Method

We collected data from a total of six groups of two participants each for a total sample size of $N = 12$. Each group of participants spent five days in the laboratory. The experiment comprised a single factor (Condition – No UAS vs. Low UAS Integration vs. High UAS Integration) within-subjects repeated measures design. During the No UAS condition, the air traffic scenario contained only manned aircraft. During the Low UAS Integration condition, eight UAS operations were integrated with manned aircraft operations. In the High UAS Integration condition, thirteen UAS operations were integrated with manned aircraft operations. We counterbalanced the order of conditions and participant/sector combinations.

Participants

Twelve ATCS from Level 10-12 TRACON facilities served as participants. The participants were Certified Professional Controllers (CPC) from Boston, Charlotte, Dallas/Fort Worth, Houston, Philadelphia, Seattle, and

Minneapolis TRACONs. All of the participants were males between 26 and 55 years of age (*M* = 43.3, *SD* = 11.3, *Mdn* = 48.5). The participants had worked as ATCS from 6.3 years to 33.2 years (*M* = 20.7, *SD* = 10.2, *Mdn* = 24.0) and had worked as a CPC for the FAA from 5.9 years to 29.2 years (*M* = 19.5, *SD* = 9.0, *Mdn* = 23.5). The participants had controlled traffic in a TRACON facility for 5.9 years to 24.1 years (*M* = 13.9, *SD* = 6.6, *Mdn* = 12.0) and had controlled traffic for 12 months within the past year. The participants' experience using the Standard Terminal Automation Radar System (STARS) ranged from 0 years to 14 years (*M* = 6.9, *SD* = 4.9, *Mdn* = 7.7). None of the participants had previous experience with UAS operations.

Apparatus

Hardware. Each ATCS workstation included a Barco 2K x 2K Liquid Crystal Display (LCD), a STARS keyboard and trackball, and an emulated Terminal Voice Switching and Communication System (see Figure 1). Above each radar display was an emulation of an Information Display System (IDS) presented on a 21.3″ touchscreen. A Workload Assessment Keypad (WAK; Stein, 1985) was located at each workstation. Ceiling-mounted color video cameras were located above and behind each workstation. Simulation pilots and Air Traffic Control (ATC) Subject Matter Experts (SMEs) used workstations to affect simulated aircraft movements and communications. Each simulation pilot workstation included a computer, keyboard, mouse, display of aircraft information, and communications system. The SME workstations were similar to the participant workstations.

Figure 1. Air Traffic Control Specialist (ATCS) workstations in the Research Development and Human Factors Laboratory (RDHFL).

Software. We used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) to enable the STARS interface and functionality. We used the Target Generation Facility (TGF) to provide aircraft performance models, to generate aircraft tracks based on predefined flight plans, and to enable the simulation pilot workstations. Both DESIREE and TGF provided data collection capabilities.

Airspace. The airspace comprised sectors and surrounding airspace based on the Mulford and Grove sectors of Northern California TRACON (NCT). Modification of the airspace was necessary because we recruited participants from TRACON facilities across the NAS (with the exception of NCT) and the participants had to learn the airspace in about two days. SMEs simplified the airspace by consolidating the multiple sectors that surround the Mulford and Grove sectors into North and South sectors. The airspace modification reduced the number of sector handoff symbols and radio frequencies that participants had to memorize. SMEs also removed the complex altitude shelf structure of the sectors to further simplify operations. Figure 2 depicts the airspace.

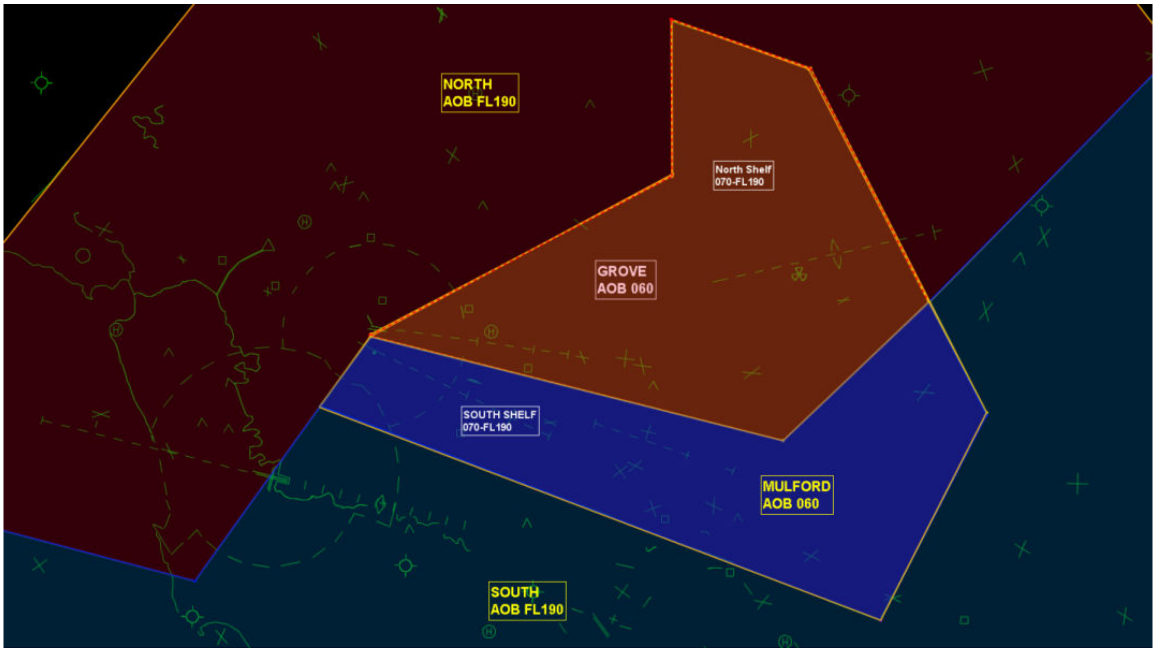

Figure 2. Mulford and Grove sectors with surrounding North and South sectors.

The participants controlled traffic in the Mulford and Grove sectors and managed arrivals into Oakland International Airport (OAK). We implemented a "West" configuration that required arrivals to use OAK runways 30, 28L, and 28R. We did not use runway 33/15. The Grove sector included airspace at or below (AOB) 6,000 ft Mean Sea Level (MSL). The Grove sector was located above the final approach course to OAK runways 28L and 28R and was responsible for directing arrivals to those runways. The Mulford sector included airspace AOB 6,000 ft MSL. The Mulford sector was located above the final approach course to OAK runway 30, and the final approach course to Hayward Executive Airport (HWD) runway 28L, and was responsible for directing arrivals to those runways. The North and South sectors were "ghost" sectors. Each ghost sector was operated by an ATC SME. The North sector managed traffic AOB 19,000 ft MSL (FL190) and between 7,000 ft MSL and FL190 over the Grove sector. The South sector managed traffic AOB FL190 and between 7,000 ft MSL and FL190 over the Mulford sector.

Air Traffic Scenarios. The No UAS (baseline) scenario comprised 91 total aircraft (56 arrivals, 25 departures, and 10 overflights). Twenty-two of the aircraft were uncontrolled VFR flights, and 69 were controlled IFR flights. There were 20 arrivals at OAK 30 and 13 arrivals and 5 departures at OAK 28R. Background traffic that impacted the participants' sectors were arrivals at San Francisco (SFO) 28R (10) and SFO 28L (13) as well as departures at SFO 28R (1), Buchanan Field (3), San Carlos (4), Reid-Hillview (2), Palo Alto (5), Livermore Municipal (1), Tracy Municipal (1), and San Jose (1) airports. The Low UAS Integration scenario was the same as the No UAS scenario, except 8 of the manned aircraft arriving at OAK 30 were replaced with UASs. The High UAS Integration scenario was the same as the No UAS scenario, except 13 of the manned aircraft arriving at OAK 30 were replaced with UASs. When UAS were present, they were evenly spaced throughout the scenario and were intermingled with other arrivals at OAK 30. All scenarios were 30 minutes in length. We created multiple versions of each scenario by changing only the aircraft callsigns to minimize the participants' ability to recognize traffic patterns within each scenario.

Results

We analyzed each data set using the appropriate repeated measures Analysis of Variance and calculated effect sizes using partial eta-squared (η_p^2). We analyzed significant main effects and interactions using Tukey's Honestly Significant Difference (HSD) test.

Aircraft Time and Distance in Sector

We used geographical sector boundaries to measure the total time and distance flown within each sector. We also counted the number of unique aircraft that flew through each sector. We measured the mean time (s) and distance flown (nm) by each unique aircraft in the Mulford and Grove sectors. An aircraft that flew into the Grove sector, then flew into the Mulford sector, and then flew back into the Grove sector was counted as a single unique operation for time and distance calculations per aircraft. There were no significant differences for any of the measures in the Grove sector.

The mean total time flown in the Mulford sector was significantly longer in the High UAS Integration condition (M = 15529 s, SD = 659 s) compared to the No UAS condition (M = 14675 s, SD = 638 s), $F(2, 22) = 7.45$, $p = .003$, $\eta_p^2 = .40$, $HSD(22) = 3069.48$. There was no significant difference in mean total time flown between the Low UAS Integration condition (M = 15003 s, SD = 791 s) and the other two conditions. The mean time flown per aircraft in the Mulford sector was significantly longer in the High UAS Integration condition (M = 345 s, SD = 15 s) compared to the No UAS condition (M = 327 s, SD = 16 s), $F(2, 22) = 6.70$, $p = .005$, $\eta_p^2 = .38$, $HSD(22) = 12.10$. There were no significant differences for mean time flown in the sector between the Low UAS Integration condition (M = 336 s, SD = 17 s) and the other two conditions.

The mean total distance flown in the Mulford sector was significantly greater in the High UAS Integration condition (M = 624 nm, SD = 30 nm) compared to the No UAS condition (M = 591 nm, SD = 27 nm), $F(2, 22) = 4.28$, $p = .027$, $\eta_p^2 = .28$, $HSD(22) = 29.90$. There was no significant difference in mean total distance flown between the Low UAS Integration condition (M = 597 nm, SD = 26 nm) and the other two conditions. The mean distance flown per aircraft in the Mulford sector was significantly greater in the High UAS Integration condition (M = 13.8 nm, SD = 0.7 nm) compared to the No UAS condition (M = 13.2 nm, SD = 0.7 nm), $F(2, 22) = 3.82$, $p = .038$, $\eta_p^2 = .26$, $HSD(22) = 0.63$. There were no significant differences in mean distance flown per aircraft between the Low UAS Integration condition (M = 13.4 nm, SD = 0.5 nm) and the other two conditions.

Communications

We recorded all voice communications to evaluate the number and duration of air-ground (pilot-to-Mulford/Grove) and ground-air (Mulford/Grove-to-pilot) Push-to-Talk (PTT) transmissions for the Mulford and Grove sectors. For the Grove sector, we found no statistically significant differences across conditions for either the number or duration of PTT transmissions, indicating that there were no differences in communication when UAS were in the Grove sector.

We measured the number and duration of the ground-air PTT transmissions from the Mulford controllers to the pilots and the air-ground PTT transmissions from the pilots to the Mulford controllers. The number of air-ground PTT transmissions differed significantly by condition, $F(2, 22) = 4.59$, $p = .022$, $\eta_p^2 = .29$. The post-hoc analysis indicated that there were more ground-air PTT transmissions at the Mulford sector in the High UAS Integration condition than in the No UAS condition, $HSD(22) = 13.13$. There was no difference in the number of ground-air PTT transmissions between the No UAS condition and the Low UAS Integration condition at the Mulford sector (see Figure 3).

Ground-air PTT transmission durations differed significantly between conditions in the Mulford sector, $F(2, 22) = 12.05$, $p = .03$, $\eta_p^2 = .52$. The post-hoc analysis indicated that ground-air PTT transmission durations in the Mulford sector were shorter in the High UAS Integration condition compared to the Low UAS Integration condition and the No UAS condition, $HSD(22) = 0.17$. There was no difference between the No UAS condition and the Low UAS Integration condition (see Figure 4).

The number of air-ground PTT transmissions in the Mulford sector did not differ significantly between conditions. However, the duration of air-ground PTT transmissions did differ significantly between conditions, $F(2, 22) = 3.95$, $p = .03$, $\eta_p^2 = .26$. The post-hoc analysis indicated that air-ground PTT transmission durations at the Mulford sector were shorter in the High UAS Integration condition compared to the No UAS condition, $HSD(22) = 0.18$ (see Figure 5). Therefore, both the controllers and the pilots made shorter transmissions when UAS were in the Mulford sector.

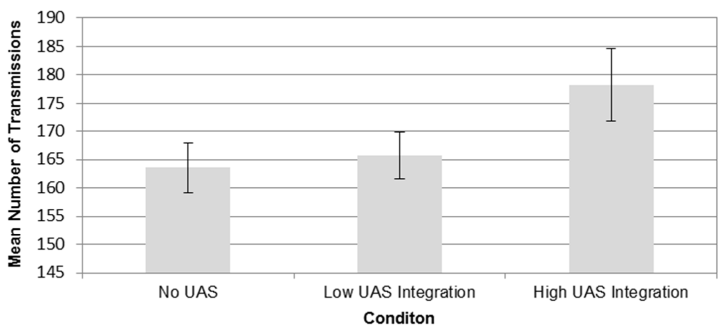

Figure 3. Mean number of ground-air PTT transmissions by Condition in the Mulford sector.

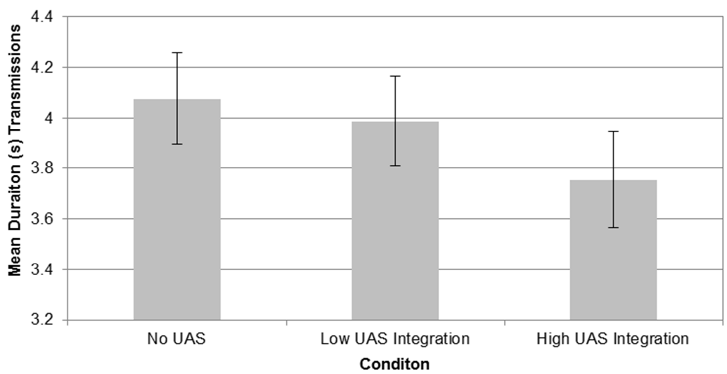

Figure 4. Mean duration of ground-air PTT transmissions by Condition in the Mulford sector.

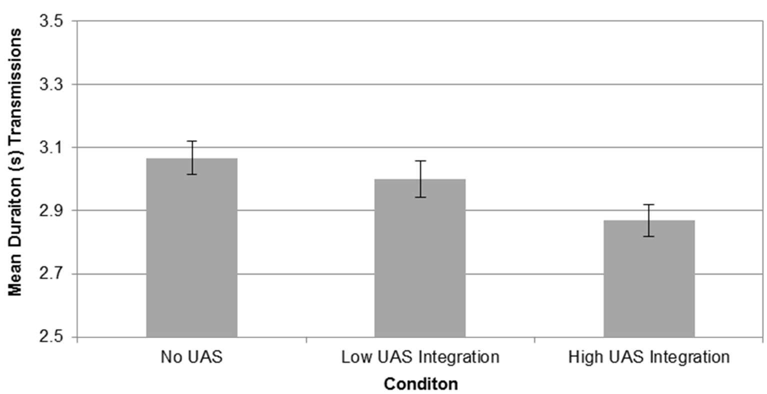

Figure 5. Mean duration of air-ground PTT transmissions by Condition in the Mulford sector.

Workload

Participants rated their subjective level of workload using the 10-button WAK (Stein 1985). If the participant did not respond within 20 seconds, the response was coded as "missing." We coded the failed responses as missing data because it is unknown if the participant was too busy to respond or simply did not notice the WAK prompt. We replaced missing responses (12/504 = 2.4%) with the mean WAK rating for the respective condition and time interval. The missing responses were randomly distributed across interval, condition, and sector.

There was a significant effect of Interval for WAK ratings at the Grove sector, $F(6, 66) = 14.77$, $p < .001$, $\eta_p^2 = .57$. Ratings increased from the first interval (4 min) to the second interval (8 min) and then increased again in the fourth interval (16 min) before decreasing in the final interval (28 min), *HSD*(66) = 1.70. There was also a significant effect of Interval for WAK ratings at the Mulford sector, $F(6, 66) = 13.99$, $p < .001$, $\eta_p^2 = .56$. Ratings increased from the first interval (4 min) to the third interval (12 min), and then remained level until the final interval (28 min), *HSD*(66) = 1.56. The Interval effects were most likely due to the design of the air traffic scenarios, which included a "ramp up" of traffic in the beginning of each scenario.

There was a significant main effect of Condition for WAK ratings in the Mulford sector due to increased subjective workload as UAS were added to the scenarios, $F(2, 22) = 5.31$, $p = .013$, $\eta_p^2 = .33$ (see Figure 6). Although differences were relatively small, WAK ratings were significantly higher in the High UAS Integration condition ($M = 4.44$, $SD = 1.87$) compared to the No UAS condition ($M = 3.62$, $SD = 1.90$) and the Low UAS Integration condition ($M = 4.00$, $SD = 1.76$), *HSD*(22) = 1.68. There was no statistical difference between WAK ratings in the No UAS condition and the Low UAS Integration condition.

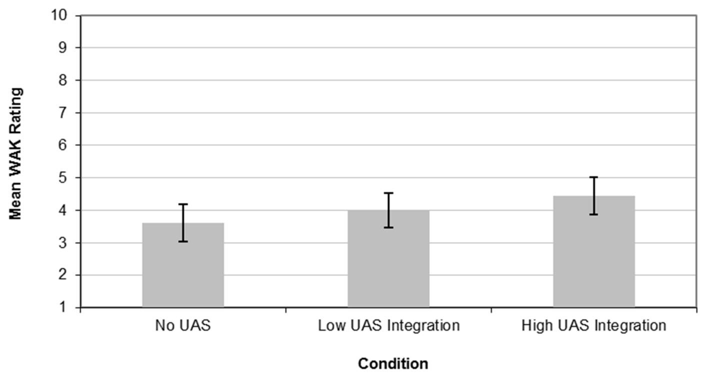

Figure 6. Mean WAK rating by Condition at the Mulford sector.

Conclusion

The Low UAS Integration condition had small but insignificant effects compared to the No UAS condition. The High UAS Integration condition had significant effects on efficiency, communications, and workload in the Mulford sector. In the High UAS Integration condition, there was an increase in the time and distance flown; there were a greater number of ground-air communications and shorter ground-air and air-ground communications; and there were higher ratings of subjective workload. Overall, a low volume of UAS operations in Class C airspace may be tenable and have relatively small effects on the airspace and ATCS.

References

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