UAS Contingency Management: The Effect of Different Procedures on ATC in Civil Airspace Operations

Lisa Fern[1] and R. Conrad Rorie.[2]
San Jose State University Research Foundation, San Jose, CA, 95112

and

R. Jay Shively[3]
NASA Ames Research Center, Moffett Field, CA, 94035

UAS currently lack key capabilities required to routinely integrate with the current Air Traffic Management (ATM) system, including standardized and predictable procedures for managing off nominal or contingency events, especially those that are specifically related to UAS and their unique communications architecture [i.e., loss of the command and control communications link(s). A simulation experiment was conducted to examine the effects of a variety of currently-employed UAS contingency procedures on sector safety and efficiency, and Air Traffic Controller (ATC) workload. ATC participants were tasked with maintaining safe separation standards in a busy Terminal Radar Approach Control (TRACON) sector that included a single UAS. During different trials, the UAS would execute one of five contingency types, including one trial with no contingency (i.e., baseline), three different contingency procedures for the loss of command and control link, and one emergency landing procedure. Objective aircraft separation and sector throughput data, workload ratings, situation awareness ratings, and subjective ratings regarding the safety and efficiency of UAS operations in the NAS were collected. Results indicated that the simulated UAS contingency procedures had no significant impact on objective measures of safety and efficiency compared to the baseline. Further, there were no significant differences in subjective workload and situation awareness ratings between the baseline and any of the contingency procedures.

I. Introduction

THE National Airspace System (NAS) has recently experienced rapid growth in the demand for Unmanned Aerial System (UAS) access and use. This demand is driven by both military and civilian UAS applications, including missions critical to military training and readiness, science, national security and defense, and emergency management. UAS access to the NAS today is obtained by issuance of a Certificate Waiver of Authorization (COA), a time consuming process that often imposes strict limitations on when and where UAS operations can take place. In addition, flying under a COA requires air traffic controllers (ATC) to block airspace, reducing the efficiency of UAS operations. Regular access to the NAS is required to achieve flexible and efficient operations that will exploit current and future UAS mission potentials.

Unfortunately, UAS currently lack key capabilities required to routinely integrate with the current Air Traffic Management (ATM) system. Among these missing capabilities are standardized and predictable procedures for managing off nominal or contingency events, especially those that are specifically related to UAS and their unique communications architecture. UAS must communicate with the Ground Control Station (GCS) via datalinks, which uplink command and control information to the aircraft from the GCS, and downlink telemetry data to the GCS from the aircraft. A “lost link” occurs when the pilot/operator loses the ability to positively control the UAS due to interruption or loss of the necessary datalinks. Lost link and other emergency events where a pilot has limited or no control of the UAS may pose an increased risk to other aircraft.

---

[1] Research Associate, Human-Systems Integration, Address/Mail Stop, and AIAA Member Grade for first author.
[2] Research Associate, Human-Systems Integration, Address/Mail Stop, and AIAA Member Grade for second author.
[3] Project Engineer, Human-Systems Integration, Address/Mail Stop, and AIAA Member Grade for fourth author.

UAS are typically pre-programmed to fly a lost link procedure (i.e., flight path) upon loss of the command and control link. Typically, these pre-programmed flight paths command the aircraft to Return to Base (RTB) where the UAS can be reacquired using a line-of-sight datalink[1]. However, these procedures can vary substantially across different platforms and mission profiles, and currently, for operations in the NAS, specific lost link and contingency procedures are not standardized. Instead, current contingency procedures are agreed upon for specific aircraft and missions under individual COAs with the FAA. In addition, pre-programmed lost link procedures are not always followed as expected by the crew, as witnessed in recent events such as the loss of a classified stealth UAS (RQ-170) in the Middle East in 2011 and the MQ-8B Fire Scout that flew into restricted airspace around Washington, D.C. in 2010[1,2]. Such events highlight the concerns surrounding the operation of UAS, and the potentially unpredictable and inconsistent nature of UAS lost link behavior is an oft-cited critical barrier to the integration of UAS into civil airspace.

Incident reports of lost link events in civil airspace include violations of assigned altitude clearances and unexpected heading changes[3]. These types of unexpected behaviors – changing course or altitude without clearance – have the potential to greatly increase ATC workload and decrease safety, which in turn may cause controllers to affect traffic flows by applying increased separation buffers between the UAS and manned aircraft. The purpose of the current study was to examine the effects of a variety of currently-employed UAS contingency procedures on sector safety and efficiency and ATC workload. It was hypothesized that contingency procedures that resulted in the most impact to nearby traffic, i.e., those with sudden and/or sizeable heading or altitude changes, would negatively affect ATC workload and performance in maintaining sector efficiency and safety.

II. Method

A. Experimental Design

The current experiment utilized a within-subjects design to study ATC performance and workload while managing UAS contingencies in high density TRACON airspace. Five levels of Contingency Behavior (C1-C5) were examined, including one trial with no contingency (i.e., baseline), three different contingency procedures for the loss of command and control link, and one emergency landing procedure. Participants received each contingency twice, resulting in 10 total scenarios. The order of presentation of Contingency Behavior was blocked by Trial number and counterbalanced across participants.

1. Contingency Behavior

The Contingency Behaviors modeled in this simulation were designed following a review of existing UAS contingency management documentation (which included an MQ-9 flight manual and the Joint Unmanned Aircraft System CONOPS) and semi-structured interviews with UAS pilots[4]. Contingency Behavior 1 (C1) contained no contingency event and served as a baseline measure of the controller's ability to manage the airspace with nominal UAS operations. The remaining four levels of the Contingency Behavior variable (C2-C5) corresponded to different, currently-employed UAS contingency procedures.

C2-C4 corresponded to three existing procedures for responding to a loss of command and control link (or, "lost link"). In both C2 and C3, the UAS was programmed to return to base via the same routing once a simulated lost link was triggered. In C2, the return to base (and subsequent 180° turn) was programmed to occur one minute following the loss of link, while in C3, the 180° turn began eight minutes following the loss of link. Following the loss of link in C4, however, the UAS maintained its pre-programmed mission flight path and returned to mission altitude one minute after the triggered event. (The UAS pilot was scripted to request a change in altitude five minutes into the scenario, forcing the eventual return to mission altitude following loss of link.)

Unlike C2-C4, C5 corresponded to an existing UAS contingency procedure for responding to a sudden and severe drop in oil pressure. In C5, the UAS entered an emergency landing procedure immediately following the emergency oil pressure alert. The UAS flew a pre-programmed approach path into March Air Reserve Base, located near the center of the experimental sector, as soon as the event was triggered. This required a descent of roughly 10,000 feet from the UAS. Thus, C2, C3 and C5 required the most drastic changes to the UAS state following the emergency (C2 and C3 requiring a 180° turn and C5 requiring a descent up to 10,000 feet). Of those three, C2 and C5 were executed one minute or less following the contingency event, while C3 occurred eight minutes after the event. In other words, C2 and C5 involved the most immediate and severe changes to the UAS, while C3 and C4 involved either less immediate or less severe changes to the UAS (see Table 1 for a summary).

Table 1. Levels of Contingency Behavior Independent Variable

ID	Event	Contingency Behavior	Time to Execute
C1	Baseline	N/A	N/A
C2	Lost Link	Return to Base	1 min
C3	Lost Link	Return to Base	8 min
C4	Lost Link	Maintain Pre-Programmed Course, Return to 14,000 feet	1 min
C5	Drop in Oil Pressure	Land at Emergency Site (March Air Reserve Base, KRIV)	Immediate

2. Trial

A second variable, Trial (T1 or T2), was included so that participants were presented with each Contingency Behavior twice. There was no systematic difference between T1 and T2.

B. Participants

Twelve retired controllers with experience in Terminal Radar Approach Control (TRACON) facilities participated in this study. Participants (all male) had an average of 25.27 years of TRACON experience, with all 12 of the participants having previously worked Southern California TRACON (i.e., East Feeder), the same airspace simulated in this study (see Table 2 for additional participant experience). Nine of the twelve participants had prior simulation experience.

C. Apparatus

1. Multi Aircraft Control Station

Multi Aircraft Control Station (MACS) is a medium-fidelity computer application designed to emulate ground- and air-side operations[5]. MACS provided the air traffic simulation environment for the study, including the simulated traffic targets, the "pseudo" pilot stations, and the controller's display. The controller's display was a Display System Replacement (DSR) presentation of Southern California TRACON airspace, with ZLA 20 designated as the active sector. The display was configured to replicate current-day, en-route controller displays, along with the corresponding data tag and conflict alerting rules. Two separate "pseudo" pilot stations allowed researchers to modify the state of all manned traffic in the sector. Controllers, "pseudo" pilots and the UAS pilot communicated via a voice over IP communication application.

Table 2. Participant Experience, by Facility.

Branch	Facility	Experience
Civilian		
	TRACON	12/12
	SoCal TRACON	12/12
	Tower	8/12
	Center	2/12
Military		
	TRACON	5/12
	Tower	4/12

2. Vigilant Spirit Control Station

Designed by the Air Force Research Laboratory (AFRL), Vigilant Spirit Control System (VSCS) is a mature ground control station operator interface that supports the control of multiple UAS and their associated payloads (Figure 1). VSCS has been used to control multiple small UAS in a variety of simulation experiments and field tests[6,7]. For the purposes of the current study, the control station was limited to single UAS control. The aircraft flew a pre-programmed flight plan, with pre-programmed emergency events as required by the experimental design. The simulated generic flight model was based on an MQ-1 Predator, with a cruise speed of 110 knots. The default flight plan had the unmanned aircraft (UA) enter the controller's sector from the north and exit from the south.

The VSCS operator served as a confederate in this study. In trials involving a contingency, operators received a visual alert within VSCS informing them of the emergency and cueing them to initiate communications with ATC. The UAS operator's interactions with ATC were scripted to ensure that the procedures for the different contingencies occurred at the same time and with the same phraseology across participant controllers.

3. Traffic Scenarios

Traffic scenarios consisted of both manned traffic, generated by the MACS software, and a single UAS, generated by the VSCS software. The traffic scenario file determined the default flight plan, altitude, and speed of each aircraft. The traffic patterns and density were developed alongside an ATC subject matter expert. Traffic density was designed to represent a busy, current day at SoCal TRACON. Roughly 50% of the manned traffic was scripted to enter ZLA 20 at a level altitude and fly one of three current-day approach routes into Los Angeles International Airport (LAX; see Figure 2). Two aircraft in the scenario were scripted to depart from Ontario International Airport (ONT), while an additional two aircraft in the scenario were scripted to land at ONT. The remaining traffic was scripted to enter the sector level and pass through ZLA 20 en route to destinations outside of ZLA20.

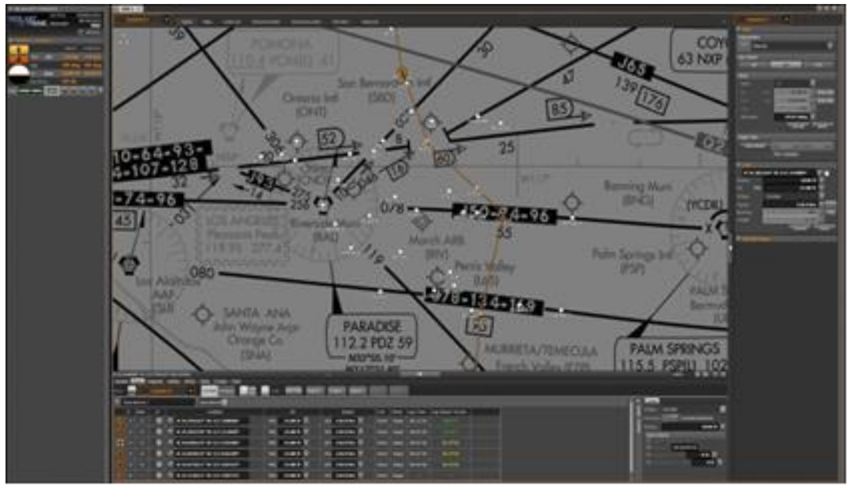

Figure 1. Vigilant Spirit Control Station (AFRL/RH). Distribution A: Approved for public release; distribution unlimited. 88ABW Cleared 3/18/2013; 88ABW-2013-1303.

The controller's main task throughout the experimental scenarios was to maintain safe separation standards while also coordinating the descent of arrivals into LAX or ONT and managing overflights. Approach airspace separation minimums of 3nm laterally and 1000ft vertically were utilized. All arrivals entered the sector level at either 17,000 or 18,000 feet. Controllers were required to descend all LAX arrivals to 10,000 feet and transition them to the adjacent sector via a single fix [SKOLL]. Controllers also descended ONT arrivals, sending them to a visual approach inside their sector. All overflights entered the sector level at or above 19,000 feet.

A single master traffic scenario file was used throughout the experiment. Five identical copies of the traffic scenario file were created and modified so that each level of the Contingency Behavior variable had its own scenario file, with identical traffic patterns but different aircraft IDs. It was the controller's responsibility to maintain separation requirements and overall airspace procedures for this single traffic problem while also dealing with UAS operations that varied between trials.

D. Procedure

1. Training

Following the completion of a demographics and consent form, participants were provided with a presentation that included a brief description of the study as well as an introduction to the simulation environment and simulation procedures. At no point during the training were the participants told that contingency events would occur during the simulation; instead, participants were informed of generic current-day UAS contingency procedures, including the ability of current UAS to return to base or maintain a pre-programmed course following the loss of command and control link. The existence of an emergency landing site inside the controller's designated sector was also detailed at this time, along with its associated approach plate.

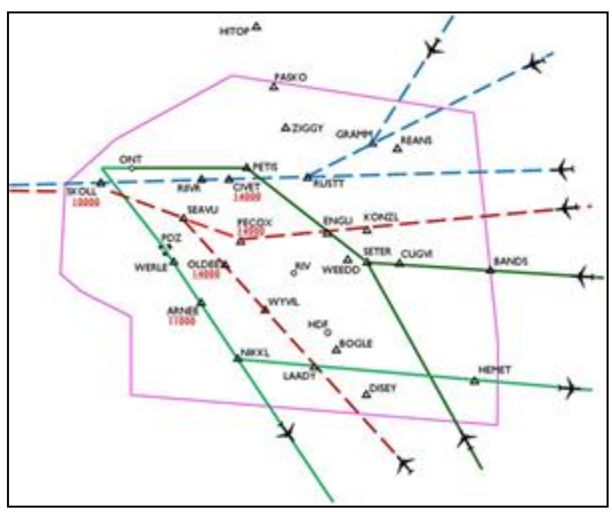

Figure 2. Graphic Departure and Arrival Routes through ZLA 20.

Following the initial presentation, the participants were given their first of three practice sessions. In the first practice session, the participant was required to successfully complete a procedural checklist while a practice traffic scenario ran in the background. The intent of the checklist was to highlight the differences between the simulation's display features (which were modeled after DSR configurations) and the display features of the Standard Terminal Automation Replacement System (STARS), which is typically used in TRACON facilities. The second practice session lasted 15 minutes and introduced "pseudo" pilots and manned aircraft into the simulation environment. The third and final practice session, also lasting 15 minutes, introduced the UAS and UAS operator to the simulation environment. No contingency procedures were introduced or detailed during the practice sessions.

2. Experimental Trials

After completing the practice session, participants completed the first block of five experimental runs, one per Contingency Behavior condition. Experimental runs lasted 17 minutes, with five minutes allotted at the conclusion of a run for workload and post-trial questionnaires. Participants received a ten minute break following their third run, and a one hour break following their fifth. An identical schedule was followed for block two.

III. Measures

A. ATC Performance

The following measures of controller performance were recorded and output by the MACS simulation software.

1. Safety

Airspace safety was measured by the number of losses of separation (LOS) events. Loss of separation was defined as a violation of the minimum separation requirement (3nm laterally and 1000 feet vertically).

2. Workload

Handoff accept time, the time elapsed between an adjacent sector's initial handoff to the experimental sector and the participant's acceptance of the handoff, was collected as a measure of workload. Longer handoff accept times were assumed to indicate a higher level of workload for the controller.

3. Efficiency

Airspace efficiency metrics included both the amount of time (sec) and the distance flown (nm) by each manned aircraft inside the sector. Larger values of either time or distance flown are assumed to correspond to lower levels of efficiency.

B. Subjective Ratings

Subjective performance data were gathered using NASA-Task Load Index (TLX), post-trial, and post-simulation questionnaires.

1. NASA-Task Load Index

The NASA-TLX is used to collect subjective assessments of operator workload along six different sub-scales (Mental Demand, Physical Demand, Temporal Demand, Performance Degradation, Effort, and Frustration)[8]. Responses were on a Likert scale of 1 ("Low") to 7 ("High"). The form was filled out following each trial in order to assess the impact of each Contingency Behavior on the workload sub-scales.

2. Post-Trial Questionnaire

Post-trial questionnaires assessed the impact of the different contingencies on the controller's ability to maintain a safe and efficient sector. Specifically, the questionnaire assessed impacts on sector efficiency and safety, situation awareness (SA), predictability of UAS behaviors, separation buffer size for the UAS relative to manned AC, and general UAS behavior relative to manned AC. All questions were rated on a Likert scale of 1 ("Strongly Disagree") to 5 ("Strongly Agree").

3. Post-Simulation Questionnaire

The post-simulation questionnaire queried controllers on the overall validity of the simulation, as well as their general assessment of the different levels of Contingency Behavior (see Appendix A). An informal debriefing session concluded the experiment.

IV. Results

The data were analyzed using a 5 (Contingency Behavior: C1-C5) X 2 (Trial: 1, 2) repeated measures analysis of variance (ANOVA). An alpha level of .05 was used for all analyses, with Bonferroni corrections made for pairwise comparisons. The results that follow discuss only Contingency Behavior, since there were no significant main effects of, or interactions with, Trial.

A. ATC Performance

1. Safety

Controllers were responsible for maintaining standard approach airspace separation minimums (3nm laterally and 1000 feet vertically) while managing their sector. Failures to maintain safe separation (i.e., LOS) were compared across Contingency Behavior (refer Table 2 above for the description of the levels of Contingency Behavior). Tests showed no significant main effect of Contingency Behavior on the number of LOS, $F(4, 44) = 0.76$, $p > .05$. C2 was associated with the highest rate of LOS ($M = 0.83$, $SE = 0.27$), while C5 was associated with the lowest rate of LOS ($M = 0.46$, $SE = 0.13$). As shown in Fig. 3, however, the average number of LOS across all conditions was relatively low ($GM = 0.60$ LOS, $SE = 0.11$ LOS), suggesting that, in general, controllers were able to successfully meet their separation requirements regardless of Contingency Behavior.

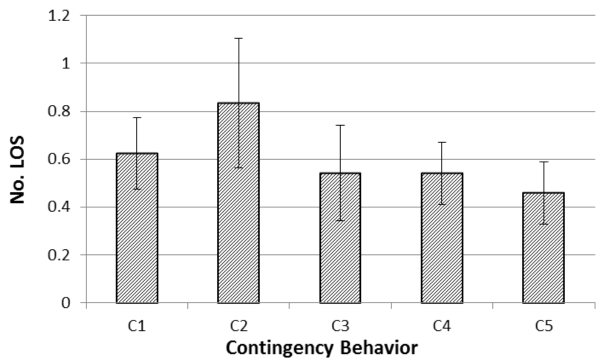

Figure 3. Average Number of Losses of Separation by Contingency Behavior.

2. Workload

Handoff accept time was collected as a measure of controller workload. Analysis revealed that Contingency Behavior had no significant main effect on handoff accept time, $F(4, 44) = 1.83$, $p > .05$ (see Fig. 4). The average handoff accept time observed in this simulation was relatively consistent across all conditions; C4 was associated with the shortest average handoff accept time ($M = 57.50$ sec, $SE = 2.30$ sec), while C5 was associated with the longest accept time ($M = 62.71$ sec, $SE = 3.30$ sec), a difference of only 5.21 sec.

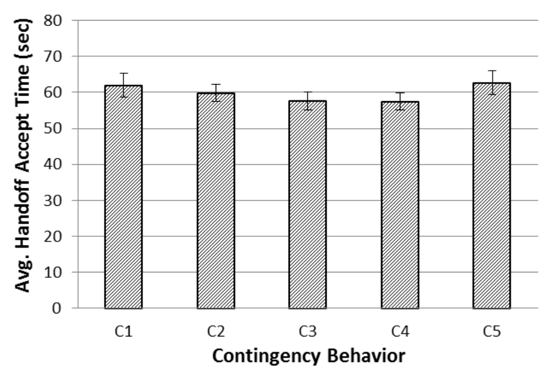

Figure 4. Average Handoff Accept Time by Contingency Behavior.

3. Efficiency

Distance through sector and time through sector were collected as measures of sector efficiency. Contingency Behavior had no significant main effect on distance through sector, with the average distance through sector remaining largely unchanged across conditions, $F(4, 44) = 1.36$, $p > .05$. As shown in Fig. 5, controllers were able to transition AC through their sector with extremely low variability; C2 was associated with the furthest average distance flown ($M = 35.97$ nm, $SE = 0.09$ nm), while C3 was associated with the shortest average distance ($M = 35.74$ nm, $SE = 0.13$ nm), a difference of only 0.23 nm.

Average time through sector was also analyzed as a measure of efficiency. Contingency Behavior once again failed to have any significant effect on time through sector, $F(4, 44) = 1.42$, $p > .05$. As shown in Fig. 6, controllers were found to move aircraft through their sector at a remarkably consistent rate. C1 was associated with the most time spent inside the sector ($M = 466.00$ sec, $SE = 3.63$ sec), while C3 was associated with the least amount of time ($M = 457.75$ sec, $SE = 3.73$ sec), a difference of 8.25 sec.

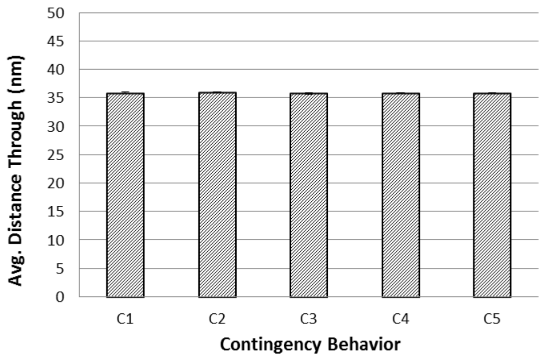

Figure 5. Average Distance Through Sector (nm) by Contingency Behavior

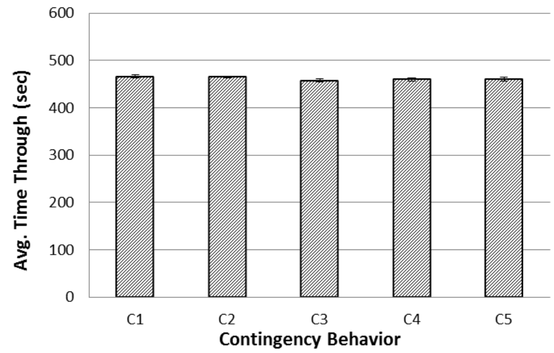

Figure 6. Average Time Through Sector (seconds) by Contingency Behavior.

B. ATC Subjective Ratings

Subjective performance data were gathered using NASA-Task Load Index (TLX), post-trial, and post-simulation questionnaires.

1. NASA-TLX

Participant responses to the NASA-TLX were also analyzed using a 5 (Contingency Behavior) x 2 (Trial) repeated-measures ANOVA. Results showed no significant main effect for Contingency Behavior, $F(4, 44) = 1.63$, $p > .05$. As shown in Fig. 7, participants indicated a level of workload that roughly equated to "Average," with very little variability between the five levels of Contingency Behavior. C3 was associated with the least amount of workload ($M = 3.64$, $SE = 0.43$), while C1 corresponded to the highest self-ratings of workload ($M = 4.02$, $SE = 0.33$).

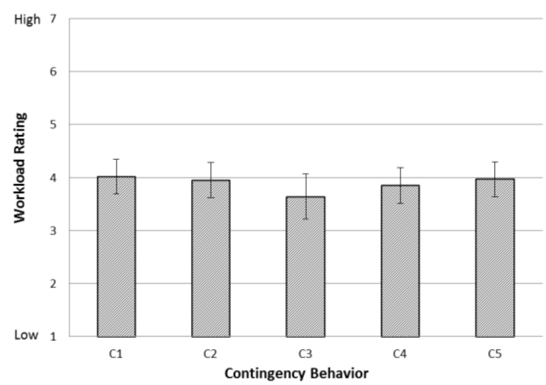

Figure 7. Mean NASA-TLX Responses by Contingency Behavior

2. Post-Trial Questionnaire

The post-trial questionnaire was administered following each run with a contingency event (i.e., C2-C5). The post-trial form was issued in order to assess controller ratings on the impact of each Contingency Behavior on

Table 3. Mean Response to Post-Trial Questionnaire, by Question.

Question	Mean (SE)
1. The contingency procedure that the UAS used in the previous trial did not impact my ability to efficiently manage my airspace	3.06 (0.42)
2. The contingency procedure that the UAS used in the previous trial did not impact my ability to safely manage my airspace	3.03 (0.43)
3. The contingency procedure that the UAS used in the previous trial did not impact my ability to meet separation requirements in my sector	3.22 (0.40)
4. The contingency procedure that the UAS used in the previous trial did not impact my ability to meet flow requirements in my sector	3.14 (0.39)
5. The contingency procedure that the UAS used in the previous trial did not impact my level of situation awareness	3.33 (0.40)
6. The contingency procedure that the UAS used in the previous trial led to predictable actions by the aircraft	3.56 (0.35)
7. I provided the same size buffer for the UAS as I did for manned aircraft	4.16 (0.25)
8. The UAS' behavior in this trial did not significantly differ from other types of manned aircraft	3.44 (0.38)

various aspects of their task. Participants were asked to what extent they agreed with the provided statement. A scale of 1 ("Strongly Disagree") to 5 ("Strongly Agree") was used, with a response of 3 corresponding to "Neutral."

As shown in Table 4, participant responses fell within 3.00 and 4.00 for seven of the eight questions. Question 7 was the only statement that resulted in a mean response greater than 4.00. On average, participants selected the option "Somewhat Agree" when asked if they gave the UAS a separation buffer equal in size to the separation buffer they provided manned aircraft.

3. Post-Simulation Questionnaire

A post-simulation questionnaire was provided to participants at the conclusion of the experiment (see Appendix A). The questionnaire asked a variety of questions regarding the study as a whole, a few of which will be summarized below.

Questions 8 and 9 asked participants, on a scale of 1 ("Strongly Disagree") to 5 ("Strongly Agree"), whether or not they believed that the presence of UAS in civil airspace would have no impact on the efficiency or safety of the overall national airspace system. Participants responded with 3.42 and 3.58, respectively, both falling between "Neutral" and "Somewhat Agree."

Question 20a asked participants to select the percentage of time they felt the UAS required special handling (0, 25, 50, 75 or 100%). Participants responded, on average, with 43.75%, suggesting that the UAS required unique management slightly less than half of the time. However, question 20c had participants rank on a scale of 1 ("Much Less") to 5 ("Much More") how much special handling the UAS required compared to manned aircraft. The mean response was 3.42, which corresponded to a rating of "Same" on the provided scale.

Three different questions on the post-simulation form (Questions 21-23; one each for safety, efficiency and workload) allowed participants to rank the different Contingency Behaviors in order of preference. Mean responses were identical for all three questions (from *Most Favorable* to *Least Favorable*):

(1) C4 [Maintain Pre-Programmed Course and Return to Mission Altitude]
(2) C3 [Return to Base in 8 minutes]
(3) C2 [Return to Base in 1 minute]
(4) C1 [Emergency Landing]

In other words, controllers agreed that C4 negatively impacted their task the least, while C3, C2 and C5 were increasingly detrimental to their performance.

V. Discussion

The current study examined the impact of existing UAS contingency procedures on sector and ATC performance. The controller was responsible for managing Southern California TRACON – a sector with a high traffic load and a requirement to transition all LAX arrivals to a single altitude and fix. Added to the controller's task was the introduction of a single UAS, whose filed route had the aircraft enter the sector from the north and exit from the south. In non-baseline conditions, the UAS entered an unexpected contingency procedure. The contingencies themselves were modeled after existing lost link and emergency landing procedures presently utilized by UAS (see Table 2).

While the authors hypothesized that the contingencies that resulted in the most sudden and/or sizeable maneuvers would negatively impact ATC performance workload, this was not supported by the objective data. Contingency Behavior was found to have no positive or negative impact on the collected performance metrics: losses of separation, handoff accept times, time through sector, and distance through sector all failed to result in any significant differences. It is worth noting that, not only were there no significant differences between the four simulated contingencies, but the contingencies also failed to result in any significant differences from the baseline condition (C1), where no contingency was injected. The objective metrics therefore strongly suggest that the presence of the UAS – with or without a contingency – made very little impact on the controller's performance.

Despite the lack of objective data to support the hypothesis that sudden and excessive heading and altitude changes would most negatively impact safety and efficiency in the sector, ATC preference ratings were in the direction that would be expected by this hypothesis. On ratings of safety, efficiency, and workload, the controllers overwhelmingly preferred C4, in which the UAS stayed on its planned flight path and changed altitude by 1000 feet to reach mission altitude. This Contingency Behavior involved the least amount of maneuvering from the aircraft. The least preferred Contingency Behavior was the emergency landing condition, whereby the UAS executed a landing procedure that required it to change course and descend through several traffic routes. For the two "return to base" Contingency Behavior conditions, C3 was preferred over C2, where the only difference was the amount of lag time before the UAS turned around (eight minutes and one minute, respectively). Thus, the participants appear to have ranked their preferred contingencies in order from least impactful to most impactful with respect to the relative immediacy and size of the maneuver.

However, the lack of significant differences in the data needs to be interpreted cautiously. There are a number of potential reasons as to why the Contingency Behaviors may have had little impact on participant performance, besides the interpretation that they do not affect ATC. The low number of safety violations and the near total absence of variability in the efficiency metrics highlight both the flexibility and the proficiency of the controllers that participated in this study. In the debriefing sessions that occurred at the end of the experiment, participants remarked that, while the overall task required a high level of workload, the UAS itself contributed very little to their perceived workload level. Furthermore, participants noted that controllers that have worked SoCal TRACON are very likely to have previously dealt with special aircraft in their airspace, since slow-moving aircraft (e.g., helicopters) are consistently granted access to the sector for FBI and DEA operations. Given the extensive experience the controllers that participated in this study had in the airspace, it is likely that the UAS contingency operations were not as disruptive as had been expected. Also noted in the debriefing sessions was the fact that SoCal TRACON is known to attract, not only highly talented ATC, but controllers that enjoy a high level of workload. This is due to the fact that SoCal TRACON is a notoriously active sector; one that is responsible for moving traffic to and from one of the busiest airports in the world.

Results from the subjective questionnaires further support the contention that the controllers in this study had skill sets that were robust enough to adapt to current-day UAS contingency procedures. Self-reports of workload on the NASA-TLX displayed no significant difference between the baseline condition (C1) and the trials that included a contingency event (C2-C5). Consistent with comments during the debriefing sessions, the high traffic density and the requirement to coordinate the descent of all LAX arrivals is what most likely kept controller's workload high across all trials. Furthermore, a response of "Neutral" to the vast majority of the questions presented in the post-trial and post-simulation questionnaires highlights the minimal impact of the UAS in this study. Participants overwhelmingly believed that UAS operations had little effect on their ability to manage their sector safely and efficiently or on their ability to maintain desirable levels of situation awareness and workload.

In addition to participant characteristics, some limitations in the experimental design may have contributed to a lack of significant findings in the objective data. First, the simulation did not examine the sector without a UAS present. It is possible that the true "baseline" is when no UAS is present, and that the introduction of the UAS to the sector significantly increased workload to maximum level, and decreased performance to a minimum level, such that the Contingency Behaviors had no further effect. Previous research has indicated that UAS pilots are able to comply immediately and appropriately to ATC instructions and have sufficient knowledge of airspace and procedures, suggesting that whether an aircraft is manned or unmanned should be transparent to ATC and should not significantly increase workload[9]. However, there has not been a direct comparison of airspace operations with and without a UAS present. Second, while a busy sector was used, the study examined only a single traffic scenario and one type of airspace class with no scripted conflicts. Changing airspace classes, traffic flows and introducing conflicts would add significant complexity to the controllers' task, such that the additional presence of a UAS and UAS contingency procedures would likely have more impact. Third, the focus of the study was on existing contingency procedures, most of which were agreed to by the FAA through the COA process and were purposely designed to reduce impact on ATC and the ATM system. The lack of any intentionally impactful scenario (e.g., UAS immediately enters a loiter pattern following loss of link) makes it impossible to say with certainty that the lack of findings in the objective data were due to our experimental design and not issues with the sensitivity of our workload, safety and efficiency metrics.

VI. Conclusion

Overall, the current study found a lack of significant impact of UAS contingencies on ATC efficiency, safety, and workload. Although there were no significant differences between contingencies in the objective and workload data, participants preferred contingencies that had the least impact on nearby traffic flows over those that involved sudden and/or large changes in altitude and heading. These results suggest that future, standardized, contingency procedures should minimize heading and altitude changes to the extent possible. However, before these results can be generalized to UAS concepts of operations in the NAS, future research needs to address the limitations of the current study, with comparable results on safety and efficiency.

Appendix A

ATC Post-Sim Questionnaire

Please circle the number that most accurately describes your opinion. If you do not understand a question, ask the researcher for clarification.

		Strongly Disagree	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
1.	The presence of the UAS did not impact my ability to **efficiently** manage my airspace	1	2	3	4	5
2.	The presence of the UAS did not impact my ability to **safely** manage my airspace	1	2	3	4	5
3.	The presence of the UAS did not impact the level of **workload** required to manage my airspace	1	2	3	4	5
4.	The traffic density in my sector was realistic relative to current-day operations	1	2	3	4	5
5.	The flow of traffic in my sector was representative of LAX east feeder traffic	1	2	3	4	5
6.	Using a DSR at my station did not impact my performance during this study	1	2	3	4	5
7.	Using a standard QWERTY keyboard as my method of input did not impact my performance during this study	1	2	3	4	5
8.	In my opinion, allowing UAS to fly in civil airspace would not impact the **efficiency** of the overall system	1	2	3	4	5
9.	In my opinion, allowing UAS to fly in civil airspace would not impact the **safety** of the overall system	1	2	3	4	5
10.	In my opinion, the workload required in this experiment was representative of workload as an on-duty approach controller	1	2	3	4	5
11.	The UAS pilot responded to commands in a timely manner	1	2	3	4	5
12.	The pseudo pilots responded to commands in a timely manner	1	2	3	4	5
13.	The UAS operator had sufficient knowledge of airspace and procedures to comply with issued commands	1	2	3	4	5
14.	The pseudo pilots had sufficient knowledge of airspace and procedures to comply with issued commands	1	2	3	4	5
15.	The performance characteristics of the UAS (e.g., speed, rate of climb/descent) did not create problems while managing my sector	1	2	3	4	5

16.	The lost link contingency procedure of returning to base immediately did not impact my ability to manage my sector	1	2	3	4	5
17.	The lost link contingency procedure of returning to base after an 8 minute period did not impact my ability to manage my sector	1	2	3	4	5
18.	The lost link contingency procedure of maintaining course and returning to mission altitude did not impact my ability to manage the sector	1	2	3	4	5
19.	The emergency landing contingency procedure did not impact my ability to manage the sector	1	2	3	4	5

20 a. What percentage of time did the UAS require special handling? (Please circle best answer)

100%
75%
50%
25%
0%

20 b. Please describe the type of special handling the UAS required, if any:

____

____

20 c. How much special handling was required for the UAS compared to the amount of special handling typically required by manned aircraft? (Please circle best answer)

1	2	3	4	5
Much Less	Somewhat Less	Same	Somewhat More	Much More

21. Please rank all of the following contingency procedures in order of their effect on your level of workload (1 = lowest workload, 4 = highest workload).

☐ Turn Around Immediately

☐ Turn Around After 8 Minutes

☐ Continue on Path, Return to Mission Altitude

☐ Emergency Landing

22. Please rank all of the following contingency procedures in order of their effect on the safety of the sector (1 = most safe, 4 = least safe).

☐ Turn Around Immediately

☐ Turn Around After 8 Minutes

☐ Continue on Path, Return to Mission Altitude

☐ Emergency Landing

23. Please rank all of the following contingency procedures in order of their effect on the efficiency of the sector (1 = most efficient, 4 = least efficient).

☐ Turn Around Immediately

☐ Turn Around After 8 Minutes

☐ Continue on Path, Return to Mission Altitude

☐ Emergency Landing

24. What was your strategy during the lost link contingency procedure where the UAS returned to base immediately?

____

____

25. What was your strategy during the lost link contingency procedure where the UAS returned to base after 8 minutes?

____

____

26. What was your strategy during the lost link contingency procedure where the UAS maintained course and returned to mission altitude?

____

____

27. What was your strategy during the critical system failure contingency procedure where the UAS immediately entered an emergency flight path into KRIV?

References

[1]Majumdar, D., "Analysts: Lost USAF UAV Likely Malfunctioned," *Defense News*, URL: http://www.defensenews.com/article/20111206/DEFSECT01/112060303/Analysts-Lost-USAF-UAV-Likely-Malfunctioned [cited March 5, 2013].

[2]Cavas, C. P., "Lost Navy UAV enters Washington Airspace," *Defense News*, URL: http://www.defensenews.com/article/20100825/DEFSECT01/8250310/Lost-Navy-UAV-Enters-Washington-Airspace [cited March 5, 2013].

[3]National Aeronautics and Space Administration, Avaition Safety Reporting System: ASRS, "Unmanned Aerial Vehicle (UAV) Reports," 2012.

[4]Joint Unmanned Aircraft Systems Center of Excellence, "Joint Concept of Operations for Unmanned Aircraft Systems Airspace Integration," 2011, Washington, D.C.

[5]Prevot, T., "Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi Aircraft Control System MACS," *Proceedings of the HCI-Aero*, 2002, pp. 149-154.

[6]Feitshans, G. L., Rowe, A. J., Davis, J. E., Holland, M., & Berger, L., "Vigilant Spirit Control Station (VSCS)—'The Face of COUNTER'," *Proceedings of AIAA Guidance, Navigation and Control Conf. Exhibition*, AIAA, Washington, DC, 2008, No. 2008-6309.

[7]Taylor, R. M., "Human Automation Integration for Supervisory Control of UAVs," *Proceedings RTO-MP-HFM-136: Virtual Media for Military Applications*, Neuilly-sur-Seine, France, 2006, pp. 12-1 – 12-10.

[8]Hart, S. G., & Staveland, L. E., "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," *Human Mental Workload*, *1*(3), 1988, pp. 139-183.

[9]Fern, L., Kenny, C., Shively, R. J., & Johnson, W., "UAS Integration into the NAS: An Examination of Baseline Compliance in the Current Airspace System," *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, 2012.