technical note technical

UAS Operational Assessment:

Contingency Operations

Simulation Report

Bina Pastakia, FAA
James Won, Ph.D., MIT Lincoln Laboratory
Randy L. Sollenberger, Ph.D., FAA
Derrick Aubuchon, Flight Research Associates
Steve Entis, Analytical Technology Application Corporation
Lacey Thompson, FAA

September 2015

DOT/FAA/TC-TN15 /55

This document is available to the U.S. public through the National Technical Information Services (NTIS), Springfield, Virginia 22161.

This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency. This document does not constitute FAA policy. Consult the FAA sponsoring organization listed on the Technical Documentation page as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center's Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-TN15/55	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle UAS Operational Assessment: Contingency Operations		5. Report Date September 2015 6. Performing Organization Code ANG-C35
7. Author(s) Bina Pastakia, FAA; James Won, PH.D., MIT Lincoln Laboratory, Randy L. Sollenberger, Ph.D., FAA; Derrick Aubuchon, Flight Research Associates; Steve Entis, Analytical Technology Application Corporation; Lacey Thompson, FAA		8. Performing Organization Report No.
9. Performing Organization Name and Address U.S. Department of Transportation Federal Aviation Administration Unmanned Aircraft Systems Engineering Branch, ANG-C35 William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Emerging Technologies Group, AJV-115 490 L'Enfant Plaza, SW Suite 3200 Washington, DC, 20024		13. Type of Report and Period Covered Technical Note October 2012 – September 2015 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Federal Aviation Administration (FAA) is in the process of investigating the challenges pertaining to the integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS). In order to advance this integration, validated operational standards and policies need to be established through determination of parameters, operations, and procedures that define acceptable UAS behavior. This research addresses the issues associated with UAS integration in the context of contingency operations. Through a high-fidelity, real-time, human-in-the-loop (HITL) simulation, the effects of UAS contingency events were evaluated and analyzed. The contingency events included loss of link, loss of air traffic controller (ATC) communications, "flyaway", flight termination, and emergency divert. Specifically, the research evaluated the impact of these events on system safety and efficiency in the NAS, and the impact on controller behavior and workload. Scenarios were developed for the Northern California TRACON (NCT) airspace, and a "Predator-like" UAS simulated the UAS characteristics of interest. A total of 12 air traffic controllers from NCT participated in teams of two for the arrival configuration scenarios, and a total of 12 controllers participated in teams of three for the departure configuration scenarios. There were a total of 17 unique scenarios (3 baseline scenarios without UAS, and 14 contingency scenarios with UAS). The collected measures included safety, efficiency, radio communications, and controller workload, in addition to subjective assessments and observer ratings. Study results illustrated the potentially adverse effects that UAS contingency events can have on NAS operations and ATC. At the same time, the study demonstrated the resiliency and capability of current air traffic controllers in mitigating these effects and maintain the priority of safety above all other factors. Recommendations on UAS predictability, lost link procedures, UAS communications, lost link beacon codes, ATC operational priorities, and ATC training were also captured. Future work is required to evaluate these potential solutions in order to provide effective, specific guidance to support UAS integration.

17. Key Words UAS, Unmanned Aircraft Systems, Predator, Northern California TRACON, NCT, Class C, Contingency Operations, Lost Link, UAS Predictability		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page intentionally left blank.

Executive Summary

Background

Although Unmanned Aircraft (UA) have been flying in domestic non-segregated airspace for more than ten years, their use in civilian airspace is currently restricted. The quantity, quality, and complexity of Unmanned Aircraft Systems (UAS) have increased drastically in the past few years, and the use of UAS in civilian airspace is expected to increase as new uses and technologies are developed, and the National Airspace System (NAS) evolves with Next Generation (NextGen) capabilities.

Currently, public UAS applicants (federal, state, and local agencies) require a Certificate of Authorization (COA) from the Federal Aviation Administration (FAA) to fly outside restricted airspace or warning areas. Civil applicants such as manufacturers and academia require a special airworthiness certificate issued by the FAA for each UAS model. COAs are written authorizations that specify the limitations or special provisions required for the safe operation of the UAS in the NAS. COAs are required because the unmanned aircraft (UA) are not compliant with certain sections of Title 14 of the Code of Federal Regulations (CFR). For instance, the absence of an onboard pilot means that the "see and avoid" and "right of way" provisions of 14 CFR Part 91.113 cannot be satisfied. Without an onboard pilot, there is significant reliance on the Command and Control (C2) data link and a greater emphasis on the loss of functionality associated with off-nominal events such as loss of link.

Current UAS operations are limited in order to minimize risk to the public until standards, regulations, and policies can be developed for safe integration into the NAS. The ultimate goal of the UAS community is to support advanced integration of UAS into the NAS, leading to "file and fly" capabilities that enable routine UAS operations in non-segregated civil airspace. Therefore, validated operational standards, policies, and procedures are required, particularly in the case of off-nominal (contingency) operations, to maintain safety and efficiency in the NAS and minimize the impact on Air Traffic Control (ATC).

Objectives

This research examines the impact of lost link and other contingency conditions on UAS operations in the NAS. Results help identify ATC requirements for providing service under contingency operations, inform ATC standard operating procedures for UAS in FAA Joint Order (JO) 7110.65, Chapter 7, and identify ATC service standards when controlling UAS under contingency operations.

This study was intended to be a foundational study, building a robust baseline for current operations off of which follow-on work could look to the future and more solution-oriented operations.

Methods

Scenarios were developed to emulate the Northern California Terminal Radar Approach Control (TRACON)(NCT) and the relevant surrounding environment, which includes Class A, B, C, and D airspace. A UAS model similar to a General Atomics-Aeronautical Systems Inc. Predator was chosen to represent the UAS characteristics of interest, and three distinct airspace

configurations (one departure configuration, two arrival configurations) were simulated for this study. Each configuration was considered independently, and therefore, separate analyses were conducted for each of these configurations of interest. Within each, all air traffic controller positions were staffed by controllers from NCT in an effort to maintain emulation of normal, realistic operations within their representative sectors. One coordinator position and two sector positions were simulated in the departure configuration. Two sector positions were simulated in one arrival configuration, and one sector and one handoff position were simulated in the other.

For each configuration, analyses were conducted to compare the effects of each UAS contingency scenario to a baseline scenario that did not include a UAS. The experiment design does not intend to suggest that a contingency event would occur every time a UAS appears, but was purposely developed to address the study's objective of comparing current NAS operations with UAS contingency operations in the NAS.

Since each configuration was considered and analyzed separately, a unique baseline scenario was generated for each configuration, resulting in three distinct analyses. The contingency events simulated for each configuration include:

1. Loss of the C2 Link and Loss of ATC Communications: The UA Pilot In Command (PIC) cannot control or receive status information on the UA or use normal channels to communicate with ATC
2. Loss of ATC Communications: The UA PIC cannot communicate with ATC on the designated frequency, but the C2 link is maintained
3. Fly-away: The UA does not follow its pre-programmed lost-link profile during a lost-link event
4. Flight Termination: The UA experiences a mechanical failure that results in a flight termination
5. Emergency Divert: The UAS diverts to a location other than the original flight plan destination due to a closed runway
6. Loss of C2 Links with Multiple UAs and Loss of ATC Communications: Two UAs simultaneously lose C2 links and Radio Frequency (RF) communications with ATC
7. Engine Failure: The UA experiences a progressive mechanical failure that results in a total loss of engine power, and eventual flight termination

The simulation was conducted at the NextGen Integration and Evaluation Capability (NIEC) laboratory at the FAA William J. Hughes Technical Center (WJHTC). Twenty-four controllers from the target population, the Mulford/Grove and Richmond/Sutro sectors in the NCT airspace, participated in the simulation. The research team and NCT participants conducted simulations for ten weeks between January and May of 2014. During the simulation, two ATC Subject Matter Experts (SMEs) served as ghost controllers for adjacent sectors, simulating all peripheral and inter-facility coordination, and as the controlling authority for the surrounding and overhead airspace. One ATC SME served the role of front line manager, and two ATC SMEs served as expert observers. One UAS pilot and nine simulation pilots operated the aircraft in the scenarios. (In the scenario with multiple UAS, the same UAS pilot operated both UAS.) Chase planes were

assumed but not simulated on the ATC radar scope. See Section 4.3 Assumptions and Constraints for more detail.

Objective and subjective data was collected to evaluate the impact of contingency operations on ATC. The collected data includes safety measures, efficiency measures, and ATC measures (workload data, push-to-talk transmission data, and subjective questionnaire data).

Results

Generally, UAS contingency operations appeared to contribute to an overall increase in the air traffic controllers' workload. This was reflected in their real-time and post-scenario workload assessments, as well as in increased controller communications with pilots and front line managers. The increased workload led to potentially degraded situation awareness and may have increased difficulty in dealing with the scenario, as expressed in the post-scenario questionnaires. These assessments were primarily a result of the perceived unpredictability of the UAS contingency operations, as expressed by controllers.

Such assessments may indicate that UAS contingency operations would contribute to reduced levels of system safety. However, this research uncovered no significant impact of contingency operations on objective measures of system safety, providing a strong indication that controllers were able to maintain safety despite the adverse conditions that they encountered.

These findings support the ATC mandate of maintaining safety as the highest priority as directed in Paragraph 2-2a of FAA Order 7110.65V:

> *Give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment must be used in prioritizing all other provisions of this order based on the requirements of the situation at hand.*

The controllers, demonstrating full compliance with the mandate, used common controller techniques to delay traffic in order to maintain safety. In most cases the increased number of delays resulted in aircraft spending more time and flying longer distances within each sector, while the controllers worked to "get it [the sector] back to a manageable level," as expressed by one participant. These effects on efficiency were observed in all three configurations, which all controllers recognized as, while not desirable, an acceptable consequence of prioritizing safety.

Conclusions and Recommendations

This research showed the potentially adverse effects that UAS contingency events can have on NAS operations and ATC. At the same time, the project demonstrated the resiliency and capability of current air traffic controllers in mitigating these effects and maintaining the priority of safety above all other factors. Overall, while acknowledging the challenges, UAS integration was generally viewed optimistically. Controllers indicated that enhanced predictability of contingency procedures and operations would greatly support integration of UAS into the NAS and minimize the impact on efficiency, while maintaining system safety. In addition to recommendations on UAS predictability, recommendations on lost link procedures, UAS communications, lost link beacon codes, ATC operational priorities, and ATC training and familiarization were also captured. Future work is required to substantiate these indications, and provide specific guidance to support UAS integration.

This page intentionally left blank.

Table of Contents

Executive Summary v
Acknowledgments xv
1 Introduction 1
1.1 Background 1
1.2 Objective 3
1.3 Scope 4
2 Description of Proposed Research Task 5
2.1 Statement of Research Requirements 5
2.2 Research Questions and Hypotheses 5
2.2.1 Outcomes/Benefits 6
3 Task Roles and Responsibilities 7
4 Method 8
4.1 Participants 8
4.2 Research Team Roles and Responsibilities 8
4.2.1 Ghost Controller and Ghost Coordinator 8
4.2.2 TGF UAS Pilot 9
4.2.3 TGF Simulation Pilots 9
4.2.4 Expert Observers 9
4.3 Assumptions and Constraints 9
4.4 Equipment and Software 10
4.4.1 Hardware 10
4.4.2 Software 12
4.4.3 Workload Assessment Keypad 13
4.4.4 Audio-Video Recording System 14
4.4.5 Communications 14
4.5 Materials 18
4.5.1 Informed Consent Form 18
4.5.2 Biographical Questionnaire 18
4.5.3 Post-Scenario Questionnaire 18
4.5.4 Post-Experiment Questionnaire 19
4.5.5 Observer Rating Form 19
4.5.6 Front Line Manager Form 19
4.6 Airspace 19
4.7 Traffic Scenarios 20
4.7.1 Airspace Configuration 1 and Detailed Traffic Scenarios 25
4.7.2 Airspace Configuration 2 and Detailed Traffic Scenarios 29
4.7.3 Airspace Configuration 3 and Detailed Traffic Scenarios 40
4.8 Pre-testing 47
4.9 Design 48

4.9.1 Independent Variables 48
4.9.2 Simulation Measures 48
4.10 Procedure 50
4.10.1 Schedule of Events/Timeline 50
4.10.2 In-Briefing 51
4.10.3 Training and Practice Scenarios 51
4.10.4 Data Collection Procedure 51
5 Data Analysis Methodology 52
6 Results 53
6.1 Configuration 1 (Arrival): Grove and Grove Handoff 53
6.1.1 Safety Data 54
6.1.2 ATC Data 54
6.1.3 Efficiency Data 58
6.2 Configuration 2 (Departure): Richmond and Sutro 59
6.2.1 Safety Data 59
6.2.2 ATC Data 60
6.2.3 Efficiency Data 65
6.3 Configuration 3 (Arrival): Mulford and Grove 68
6.3.1 Safety Data 68
6.3.2 ATC Data 69
6.3.3 Efficiency Data 76
7 Discussion and Conclusions 78
8 Recommendations 83
8.1 UAS Predictability 83
8.2 Lost Link Procedure 83
8.3 Communication 84
8.4 Lost Link Beacon Code 84
8.5 ATC Operational Priority 85
8.6 Training and Familiarization 85
9 Acronyms 87
10 References 90
Appendix A: Informed Consent Statement 93
Appendix B: Biographical Questionnaire 95
Appendix C: Post-Scenario Questionnaire 97
Appendix D: Post-Experiment Questionnaire 107
Appendix E: Observer Rating Form 111
Appendix F: Front Line Manager Form 117
Appendix G: Results – Configuration 1, Grove 119
Appendix H: Results – Configuration 1, Grove Handoff 123
Appendix I: Results – Configuration 2, Richmond 127
Appendix J: Results – Configuration 2, Sutro 131

Appendix K: Results – Configuration 2, Coordinator (CI) 135
Appendix L: Results – Configuration 2A, Richmond 139
Appendix M: Results – Configuration 2A, Sutro 145
Appendix N: Results – Configuration 2A, Coordinator 151
Appendix O: Results – Configuration 3, Mulford 153
Appendix P: Results – Configuration 3, Grove 157
Appendix Q: Results – UAS with No Contingency Event 161

LIST OF FIGURES

Figure 4-1 ATCS Workstations 11
Figure 4-2 NIEC Laboratory Layout 12
Figure 4-3 Workload Assessment Keypad 14
Figure 4-4 Simulated Communication Environment 17
Figure 4-5 Configuration 1, Grove Sector Diagram 25
Figure 4-6 Configuration 1, Baseline 26
Figure 4-7 Configuration 1, Fly-away 27
Figure 4-8 Configuration 1, Lost Link 28
Figure 4-9 Configuration 1, Lost Comm 29
Figure 4-10 Configuration 2, Richmond Sector Diagram 30
Figure 4-11 Configuration 2, Diablo Sector Diagram 31
Figure 4-12 Configuration 2, Sutro Sector Diagram 31
Figure 4-13 Configuration 2, Baseline 32
Figure 4-14 Configuration 2, Lost Link-Cruise 33
Figure 4-15 Configuration 2, Flight Termination 34
Figure 4-16 Configuration 2, Lost Comm 35
Figure 4-17 Configuration 2, Fly-away 36
Figure 4-18 Configuration 2, Engine Failure 37
Figure 4-19 Configuration 2, Lost Link-Departure 38
Figure 4-20 Configuration 2, Multiple Lost Links 39
Figure 4-21 Configuration 3, Mulford Sector Diagram 41
Figure 4-22 Configuration 3, Grove Sector Diagram 42
Figure 4-23 Configuration 3, Baseline 43
Figure 4-24 Configuration 3, Lost Comm 44
Figure 4-25 Configuration 3, Fly-away 45
Figure 4-26 Configuration 3, Emergency Divert 46
Figure 4-27 Configuration 3, Lost Link 47
Figure 6-1 Configuration 1, Mean (M) Number of Losses of Separation (Grove) 54
Figure 6-2 Configuration 1, Mean NASA-TLX Ratings (Grove HO) 55
Figure 6-4 Configuration 1, Mean Self-assessment Ratings of Overall Safety (Grove) 57
Figure 6-5 Configuration 1, Mean ATCS Rating of Ability to Move AC Efficiently (Grove HO) 58

Figure 6-6 Configuration 1, Mean Number of Arrival Delays (Grove) 59
Figure 6-7 Configuration 2, Mean Loss of Separation (Richmond) 60
Figure 6-8 Configuration 2, Mean NASA-TLX Ratings (Richmond) 61
Figure 6-9 Configuration 2, Mean WAK Ratings (Richmond) 62
Figure 6-10 Configuration 2, Mean Workload Rating Due to ATCS-to-Pilot Comm (Richmond) 62
Figure 6-11 Configuration 2, Mean Number of PTT Transmissions (Richmond) 63
Figure 6-12 Configuration 2, Mean Rating of Overall Level of SA (Richmond) 64
Figure 6-13 Configuration 2, Mean Flight Time (Richmond) 66
Figure 6-14 Configuration 2, Mean Number of Requested HFRs (Richmond) 67
Figure 6-15 Configuration 2, Mean Number of Departure Delays (Richmond) 67
Figure 6-16 Configuration 3, Mean Loss of Separation (Mulford) 69
Figure 6-17 Configuration 3, Mean NASA-TLX Ratings (Mulford) 70
Figure 6-18 Configuration 3, Mean Workload Rating Due to ATCS-to-FLM Comms (Mulford) 71
Figure 6-19 Configuration 3, Mean Number of PTT Transmissions (Grove) 72
Figure 6-20 Configuration 3, Mean Rating of Overall Level of SA (Grove) 73
Figure 6-21 Configuration 3, Mean ATCS Rating of Ability to Move AC Efficiently (Mulford) 74
Figure 6-22 Configuration 3, Mean Flight Time (Grove) 76
Figure 6-23 Configuration 3, Mean Number of Arrival Delays (Mulford) 77
Figure 7-1 WAK Ratings for Duration of Scenario 79
Figure 7-2 Immediate Information Needed to Handle UAS Event 81
Figure 7-3 Follow-up Information Needed to Handle UAS Event 81
Figure Q-1 Efficiency Measures for 06:00-13:00, Configuration 1 162
Figure Q-2 WAK Ratings, Configuration 1 162
Figure Q-3 WAK Ratings, Configuration 2A 163
Figure Q-4 Efficiency Measures for 06:00-13:00, Configuration 3 164
Figure Q-5 WAK Ratings (1-7), Configuration 3 164

LIST OF TABLES

Table 2-1 Summary of Research Questions, Variables, Hypotheses and Metrics 6
Table 4-1 Sector Combinations and Frequencies 15
Table 4-2 Scenario Summary 22
Table 4-3 Simulation Measures 48
Table 4-4 Daily Schedule 50
Table 6-1 Summary of Post-Scenario Questionnaire Data 65
Table 6-2 Summary of Post-Scenario Questionnaire Data (Mulford) 74
Table 6-3 Summary of Post-Scenario Questionnaire Data (Grove) 75
Table G-1 Summary of Post-Scenario Questionnaire Data (Config 1, Grove) 119
Table G-2 Summary of Safety & Efficiency Data (Config 1, Grove) 120
Table G-3 Summary of Time/Distance/Transmissions Data (Config 1, Grove) 120
Table G-4 Summary of WAK Data (Config 1, Grove) 120

Table G-5 Summary of Observer Ratings Data (Config 1, Grove) 121
Table H-1 Summary of Post-Scenario Questionnaire Data (Config 1, Grove HO) 123
Table H-2 Summary of WAK Data (Config 1, Grove HO) 124
Table H-3 Summary of Observer Ratings Data (Config 1, Grove HO) 124
Table I-1 Summary of Post-Scenario Questionnaire Data (Config 2, Richmond) 127
Table I-2 Summary of Safety & Efficiency Data (Config 2, Richmond) 128
Table I-3 Summary of Time/Distance/Transmissions Data (Config 2, Richmond) 128
Table I-4 Summary of WAK Data (Config 2, Richmond) 129
Table I-5 Summary of Observer Ratings Data (Config 2, Richmond) 129
Table J-1 Summary of Post-Scenario Questionnaire Data (Config 2, Sutro) 131
Table J-2 Summary of Safety & Efficiency Data (Config 2, Sutro) 132
Table J-3 Summary of Time/Distance/Transmissions Data (Config 2, Sutro) 132
Table J-4 Summary of WAK Data (Config 2, Sutro) 133
Table J-5 Summary of Observer Ratings Data (Config 2, Sutro) 133
Table K-1 Summary of Post-Scenario Questionnaire Data (Config 2, CI) 135
Table K-2 Summary of WAK Data (Config 2, CI) 136
Table K-3 Summary of Observer Ratings Data (Config 2, CI) 136
Table L-1 Summary of Post-Scenario Questionnaire Data (Config 2A, Richmond) 139
Table L-2 Summary of Safety & Efficiency Data (Config 2A, Richmond) 140
Table L-3 Summary of Time/Distance/Transmissions Data (Config 2A, Richmond) 140
Table L-4 Summary of WAK Data (Config 2A, Richmond) 141
Table L-5 Summary of Observer Ratings Data (Config 2A, Richmond) 141
Table M-1 Summary of Post-Scenario Questionnaire Data (Config 2A, Sutro) 145
Table M-2 Summary of Safety & Efficiency Data (Config 2A, Sutro) 146
Table M-3 Summary of Time/Distance/Transmissions Data (Config 2A, Sutro) 146
Table M-4 Summary of WAK Data (Config 2A, Sutro) 147
Table M-5 Summary of Observer Ratings Data (Config 2A, Sutro) 147
Table N-1 Summary of Post-Scenario Questionnaire Data (Config 2A, CI) 151
Table N-2 Summary of WAK Data (Config 2A, CI) 152
Table O-1 Summary of Post-Scenario Questionnaire Data (Config 3, Mulford) 153
Table O-2 Summary of Safety & Efficiency Data (Config 3, Mulford) 154
Table O-3 Summary of Time/Distance/Transmissions Data (Config 3, Mulford) 154
Table O-4 Summary of WAK Data (Config 3, Mulford) 154
Table O-5 Summary of Observer Ratings Data (Config 3, Mulford) 155
Table P-1 Summary of Post-Scenario Questionnaire Data (Config 3, Grove) 157
Table P-2 Summary of Safety & Efficiency Data (Config 3, Grove) 158
Table P-3 Summary of Time/Distance/Transmissions Data (Config 3, Grove) 158
Table P-4 Summary of WAK Data (Config 3, Grove) 158
Table P-5 Summary of Observer Ratings Data (Config 3, Grove) 159

This page intentionally left blank.

Acknowledgments

This research project was sponsored by the Federal Aviation Administration (FAA) Emerging Technologies Team in Mission Support Services, Airspace Services Directorate. The project was accomplished with dedicated and daily support from a cross-cutting team of researchers from the FAA William J. Hughes Technical Center (WJHTC), which included Air Traffic Control Subject Matter Experts, Computer Scientists, Research Support Staff, and many others. Special thanks to FAA Manager John Warburton and UAS Integration Technical Lead Karen DiMeo (Buondonno) for providing their support and guidance in the planning, design, and execution of this effort. Thank you to Cherlynn Jones and Joe Romino for providing their expertise and advice throughout the project. Thank you to the many contributors from the Laboratory Service teams at the FAA WJHTC. Specifically we would like to thank the NextGen Integration Evaluation Capability (NIEC) staff, the Target Generation Facility (TGF) team, and the Distributed Environment for Simulation, Evaluation, and Experimentation (DESIREE) team for providing development and simulation support and excellent simulation and data collection capabilities. Special thanks also to Tyler Travis for all her project and coordination support.

We would also like to thank the management and staff at the Northern California Terminal Radar Approach Control (TRACON) (NCT) for their unwavering support during development, and their participation during the simulation. We thank Lance "Sky" King for serving as a Subject Matter Expert (SME) as a pilot for the General Atomics Predator/MQ-9 Reaper.

To those not mentioned by name, we thank you for all your efforts and support.

Jim Williams – FAA, UAS Integration Office, AFS-80

Randy Willis – FAA, Emerging Technologies Team, AJV-115

Christopher Swider – FAA, UAS Integration Office, Research and Development Section, AFS-88

Sabrina Saunders-Hodge – FAA, NextGen Research and Development Division Manager, ANG-C2

Michael McNeil – FAA, Engineering Development Services Division Manager, ANG-C3

John Warburton – FAA, Separation Standards and Analysis Branch Manager, ANG-E61

Karen (Buondonno) DiMeo – FAA, UAS Integration Technical Lead, ANG-C35

John Reinhardt – FAA, UAS R&D Integration, Internal Technical Community Representative Group (TCRG) Project Lead, ANG-C2

Paul Rumberger – FAA, UAS R&D Integration, External Partnership Program Lead, ANG-C2

Cherlynn Jones – B3 Solutions, SME

Joe Romino – B3 Solutions, SME

Paul Lunsford – A3 Technologies Inc., SME

Marcello Mirabelli – FAA, Research Pilot, ANG-C35

Dr. Todd Truitt – FAA, Engineering Research Psychologist, ANG-E25

Tyler Travis – Regulus Group, Project Support

Charles "Cliff" Johnson – FAA, General Engineer, ANG-E272

Robin Peterson-Brown – FAA, NextGen Integration and Evaluation Capability (NIEC) Lab, ANG-E142

Terence D. Moore – FAA, Air Traffic Subject Matter Expert, NIEC Lab Lead, ANG-E18

Colleen Horan – FAA, Air Traffic Control Specialist, ANG-C35

Phil Homer – General Dynamics Information Technology (GDIT), NIEC

Christian Sassi – GDIT, NIEC

Christopher Continisio – GDIT, NIEC

John Mick – GDIT, NIEC

Haijun Wu – GDIT, NIEC

Dan Fumosa – GDIT, NIEC

Samantha Fullerton – GDIT, TGF

Cynthia Salas – GDIT, NIEC

Dominic Pugliese – Advanced Sciences and Technologies, Communications (COMM)

Target Generation Facility – Hi-Tec Systems, Simulation Pilots

Ed Little – Engility, Data Storage and Archiving

Michael Levine – Engility, Technical Editor

Michelle O'Leary – Regulus Group, Technical Editor

Kerry Bowers – FAA, Program Analyst, ANG-C35

Marie Gale – Alpha-Native Services, LLC, Secretary III

Barbara Jeffries – Alpha-Native Services, LLC, Secretary III

Matthew Dworsky – The Analytic Sciences Corporation (TASC), Human Factors Specialist

Henry Dorsey – TASC, Technical Specialist

1 Introduction

This document presents the final report of the Unmanned Aircraft System (UAS) Operational Assessment: Contingency Operations study conducted by the Federal Aviation Administration (FAA) at the William J. Hughes Technical Center (WJHTC) in New Jersey. [1] A high-fidelity Human-in-the-Loop (HITL) simulation was conducted in the WJHTC NextGen Integration and Evaluation Capability (NIEC) laboratory for ten weeks between January and May of 2014. This research is one component in a portfolio of activities that supports a goal of the FAA's Technical Community Requirement Group (TCRG) to investigate issues pertaining to the integration of UAS into the National Airspace System (NAS).

As part of a cross-cutting inter- and multi- organizational UAS research team located at the WJHTC, the FAA's UAS Engineering Branch (ANG-C35) led the effort in support of tasking from the FAA Research and Development (R&D) Integration Division (ANG-C2). The team conducted a high-fidelity HITL simulation to investigate the impact of the loss of the Command and Control (C2) link on the NAS. The simulation also examined loss of Air Traffic Control (ATC) Communications (Comm) and other contingency conditions. Results will contribute to the identification of ATC requirements for providing service under contingency operations, written ATC standard operating procedures for FAA Joint Order (JO) 7110.65, Chapter 7, and Emergency Operations, as well as recommendations for future research.

1.1 Background

Although Unmanned Aircraft (UA) have been flying in domestic non-segregated airspace for more than ten years, their use in civilian airspace is currently restricted (Hu, et al, 2010). The quantity, quality, and complexity of UAS have increased drastically in the past few years, and the use of UAS in civilian airspace is expected to increase as new uses and technologies are developed, and the NAS evolves with Next Generation (NextGen) capabilities.

Currently, public UAS applicants (federal, state, and local agencies) require a Certificate of Authorization (COA) from the FAA to fly outside restricted airspace or warning areas. Civil applicants such as manufacturers and academia require a special airworthiness certificate issued by the FAA for each UAS model. COAs are written authorizations that specify the limitations or special provisions required for the safe operation of the UAS in the NAS. COAs are required because the UA are not compliant with certain sections of Title 14 of the Code of Federal Regulations (CFR). For instance, the absence of an onboard pilot means that the "see and avoid" and "right of way" provisions of 14 CFR Part 91.113 cannot be satisfied. Without an onboard pilot, there is significant reliance on the C2 data link and a greater emphasis on the loss of functionality associated with off-nominal events such as loss of link.

---

[1] A UAS is the unmanned aircraft (UA) and all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the UA. The UA is the flying portion of the system, flown by a pilot via a ground control system, or autonomously through the use of an onboard computer, communication links, and any additional equipment necessary for the UA to operate safely.

Current UAS operations are limited in order to minimize risk to the public until standards, regulations, and policies can be developed for safe integration into the NAS. The ultimate goal of the UAS community is to support advanced integration of UAS into the NAS, leading to "file and fly" capabilities that enable routine UAS operations in non-segregated civil airspace. Therefore, validated operational standards, policies, and procedures are required, particularly in the case of off-nominal (contingency) operations, to maintain safety and efficiency in the NAS and minimize the impact on ATC.

A consensus of public and civil users within the UAS community has focused on reducing current restrictions to support more routine access to the NAS. The ultimate goal of the community is to support the advanced integration of UAS into the NAS leading to "file and fly" capabilities that enable routine UA operations in non-segregated civil airspace. Therefore, validated operational standards, policies, and procedures are required for the ATC community and UAS pilots.

Unless otherwise specifically authorized, UAS operators must use visual observers, either airborne or ground-based, to comply with the see-and-avoid and right-of-way provisions of 14 CFR Part 91.113. There are many challenges to overcome before the basis for certification and operations of UAS are standardized and made routine. This includes developing methods to support the integration of UAS into the NAS without causing delays, capacity reduction, or placing the public at risk. Research is required to produce evidence for the safety case.

To understand the issues that air traffic facilities are currently experiencing, the MITRE Corporation (MITRE) was tasked by the FAA to collect an inventory of operational practices and issues that air traffic facilities are employing and encountering while working and coordinating UAS flight operations. The work focused on the En Route ATC environment and involved visiting Air Route Traffic Control Centers (ARTCCs) that have been routinely working UAS operations in the NAS. The team collected data at various facilities via questionnaires and interviews. A recurring issue identified was the lack of fundamental knowledge of UAS related concepts such as lost-link events and loitering points. The report acknowledged that while certain air traffic facilities have been accommodating UAS operations in the NAS, several issues involving ATC service provision would need to be addressed before full-scale integration is possible. The report recommended training on UAS performance characteristics and off-nominal (contingency) events, communication latency and reliability of communications with UAS, and creation of procedures and directives that allow UAS operations/ATC interaction analogous to manned flight. The report recommended more in-depth research to explore these challenges (Abrahamsen & Fulmer, 2013).

To examine the effects of currently employed UAS contingency procedures on safety, efficiency, and ATC workload, another relevant HITL study was conducted by the National Aeronautics and Space Administration (NASA) Ames Research Center. In their simulation, controllers were tasked with maintaining safe separation standards in a busy Terminal Radar Approach Control (TRACON) sector with a single UAS present. Five different scenarios were presented to participants during the trials, including one trial with no contingency (i.e., a baseline), three different contingency scenarios for the loss of the C2 link, and one emergency landing scenario. In two of the scenarios the UAS was programmed to return to base once a Lost-Link (LL) event was triggered, with one returning to base a minute after the loss of link and the other eight

minutes after the loss of link. In the third scenario the UAS maintained its preprogrammed mission flight path and returned to mission altitude one minute after the event. And in the fourth scenario, the UAS executed its emergency landing procedure immediately following an emergency oil pressure alert.

Participants were all retired controllers with experience working the simulated airspace. Scenarios ran for seventeen minutes and included busy to normal traffic based on historical facility operations. Both objective and subjective data on the effect of the operations were collected (Fern, Rorie, & Shively, 2014).

The NASA researchers hypothesized that contingencies would negatively impact controller performance, safety and efficiency of the NAS; however this theory was not supported by the results. Objective data suggested that the presence of the UAS, with or without a contingency, made little impact on controller performance. Despite a lack of objective data to support the hypothesis, low self-assessed ATC ratings appeared to be more in line with the hypothesis (Fern et al., 2014).

Although overall results indicated no significant differences, the researchers presented a number of potential possible reasons as to why contingency operations had little impact. Researchers stated that it is likely that the robust skillset and extensive experience with the simulated airspace play a part in the low number of safety violations and low variability in the efficiency metrics measured. Researchers also noted that in addition to participant characteristics, limitations in experiment design may have played a part in the lack of significant findings in the objective data. For example, the simulation did not simulate a baseline without a UAS present. The researchers indicated that it is possible that a true "baseline" is when no UAS is present because previous research has suggested that the introduction of a UAS raises workload and decreased performance to such a level that contingency operations have no further effect (Fern, Kenny, Shively, & Johnson, 2012). Researchers also noted that their study lacked variability in the type of airspace class, used a single traffic flow, and had the UAS returning to base (instead of entering a loitering pattern) all of which could have contributed to a greater impact on safety, efficiency, and controller workload. Researchers concluded that before results could be generalized, future research to address these limitations will need to be conducted (Fern et al., 2014).

In addition to the MITRE and NASA efforts, many other R&D efforts are underway to support the safe and efficient integration of UAS into the NAS. Another recent significant effort includes the Department of Defense's UAS Joint Test conducted in the summer of 2014.

To add to the studies previously conducted and currently underway, the results presented in this report provide a robust statistical baseline on specific effects of contingency operations in the TRACON environment that continue to build evidence to support the development of operational standards for ATC.

1.2 Objective

The objective of this high-fidelity real-time HITL simulation was to determine the effects of specific UAS contingency events on system safety and efficiency in the NAS, and on controller

workload. This study contributes to the identification of ATC service standards when controlling UAS under contingency conditions.

1.3 Scope

Scenarios for the high-fidelity HITL simulation were developed to emulate the Northern California TRACON (NCT) and relevant surrounding environment, which included Class A, B, C, and D airspace. A UAS model similar to a General Atomics-Aeronautical Systems Inc. Predator was chosen to represent the UAS characteristics of interest. (This Aircraft (AC) was chosen primarily for its operating characteristics (i.e., speed during climb, descent, and cruise, turn rate, etc.), its prevalence in the NAS today, and the relative ease with which it can operate near manned aircraft.) Though many possible contingency events exist, this study was scoped to include seven events defined as follows:

1. Loss of the C2 Link and Loss of ATC Communications: The UA Pilot In Command (PIC) cannot control or receive status information on the UA or use normal channels to communicate with ATC
2. Loss of ATC Communications: The UA PIC cannot communicate with ATC on the designated frequency, but the C2 link is maintained
3. Fly-away: The UA does not follow its pre-programmed lost-link profile during a lost-link event
4. Flight Termination: The UA experiences a mechanical failure that results in a flight termination
5. Emergency Divert: The UAS diverts to a location other than the original flight plan destination due to a closed runway
6. Loss of C2 Links with Multiple UAs and Loss of ATC Communications: Two UAs simultaneously lose C2 links and Radio Frequency (RF) communications with ATC
7. Engine Failure: The UA experiences a progressive mechanical failure that results in a total loss of engine power, and eventual flight termination

2 Description of Proposed Research Task

2.1 Statement of Research Requirements

A description of this research requirement is included in FAA Office of Aviation Safety (AVS) UAS 15-07, *Evaluation of Communications Strategies in the Context of UAS Operations*. Those requirements state:

> *In order to meet Congressionally-mandated milestone[s] and to achieve safe UAS integration into the NAS, the FAA must: 1) Assess UAS in the context of lost communication and explore procedures for UAS lost link in various classes of airspace and 2) Explore existing lost link responses and associated impacts to the safety and efficiency of the NAS.*
>
> *Integration of UAS in the NAS will also require analysis of abnormal flight conditions such as loss of control link, loss of pilot to controller communications, and other UAS emergency situations such as "Fly-away," which results when a UAS does not adhere to [the] pre-programmed lost link solution. Furthermore, how do UAS respond to lost communications in various classes of airspace and what safety issues result from UAS lost link responses? What is "acceptable" lost link behavior and should it be standardized? The lack of UAS standards and standard operating procedures for abnormal flight conditions will produce unintended consequences and potential reductions to safety.*
>
> *Identification of acceptable UAS lost link procedures in various classes of airspace, based on impacts to the safety of the NAS, [is needed] to inform the certification basis for UAS. This will lead to development of UAS operating standards that are safe and conform to existing NAS interoperability for lost link, lost communications, and fly-away for different classes of airspace. This research will also contribute towards identification of standards for ATC while handling UAS under abnormal flight conditions. These standards would be the basis for procedural and regulatory development.*

The TCRG requirements for this research were originally written in 2012 and approved for funding in 2013 and 2014. Based on direction from the UAS Integration Office, the requirements were expanded to explore the impacts of other contingency events in addition to lost link. These were defined as lost ATC communication, fly-away, flight termination, emergency divert, engine failure, and loss of control links with multiple UAS.

2.2 Research Questions and Hypotheses

Table 2-1 summarizes the research questions, hypotheses, and variables addressed in the study, as well as the metrics used.

Table 2-1 Summary of Research Questions, Variables, Hypotheses and Metrics

Research Questions	What is the impact of UAS contingency operations on system safety and efficiency in the NAS? What is the impact of UAS contingency events on controller workload?
Hypotheses	Safety and efficiency measures may indicate that UAS contingency events affect system safety and efficiency in the NAS Measurement of controller workload may indicate that UAS contingency events affect workload and performance Controller feedback may indicate that contingency operations affect system performance
Independent Variables	**Sector Configuration –** Configuration 1: Grove and Grove Handoff, Configuration 2 – Richmond and Sutro, Configuration 3L Mulford and Grove **Contingency Events** – Lost Link, Loss of ATC Communications, Fly-away, Flight Termination, Emergency Divert
Measures	**Safety** – Mid- Air Collisions, Near Mid-Air Collisions, Loss of Separation **Efficiency** – Arrival/Departure/En Route Delays, Canceled Requests, Re-Sequenced Arrivals, Airborne Holding, Departure Holding **Capacity** – Arrivals, Departures **Communications** – Transmissions: Controller-Pilot, Controller-Front-Line Manager (FLM) **Workload** – Workload Assessment Keypad (WAK) triggered at four-minute intervals, Late Handoffs, Late Frequency Changes, Repeating Clearances, Missed Traffic Calls, Denials of ATC Service **Subjective Assessment** – Post-scenario questionnaires and post-experiment questionnaires **Observer Rating** – Forms for ATC assessment of safe and efficient traffic flow, attention and Situation Awareness (SA), prioritizing, providing control information, technical knowledge, communicating, sector management

2.2.1 Outcomes/Benefits

The results obtained from this experiment provide data and recommendations to support the development of operating standards for various UAS contingency events in a variety of airspace classes.

Documenting the impact of contingency events in a controlled realistic setting with statistical validity provides a firm baseline for follow-on studies to identify mitigations for UAS contingency operations.

3 Task Roles and Responsibilities

The roles, responsibilities, and Points of Contact (POCs) for the organizations involved in the success of this research were as follows:

Sponsor: Unmanned Aircraft Systems Integration Office, AFS-80

POC: Chris Swider, AFS-88

POC: Randy Willis, AFS-83

The Unmanned Aircraft Systems Integration Office was the sponsoring organization responsible for providing the research requirement and funding for this project as well as providing the overall leadership and direction of the research. For this study, significant ATC SME support was also provided to the performing organization for the planning, development, and execution of the study.

ANG UAS R&D Portfolio Manager: NextGen Integration Division, ANG-C2

POC: Sabrina Saunders-Hodge, ANG-C2

The NextGen Integration Division serves as the liaison between the FAA sponsoring organization and the performing research organization. ANG-C2 is responsible for designating the performer and ensuring all milestones and performance standards for conducting the research are met.

Performing Organization: UAS Engineering Branch, ANG-C35

POC: Bina Pastakia

The FAA Task Lead and Co-Principal Investigator (Co-PI) for this project was Bina Pastakia of ANG-C35, who was responsible for overseeing the development of the task plan, experiment execution, data analysis, and report delivery. The Co-PI, with support from the research team, was also responsible for submitting monthly status reports, ensuring deadlines were met and risks mitigated, and for holding team meetings to coordinate activities. The performing team included researchers from ANG-C35, several ANG-E branches, and contract support companies.

The contract support team included James Won, Ph.D. from the Massachusetts Institute of Technology's Lincoln Laboratory (MIT LL), who served as the Co-PI on this task.

WJHTC Cross-cutting UAS Research Support Team, ANG-E

The FAA WJHTC supplied the air traffic control laboratories and all laboratory support services. Randy Sollenberger, Ph.D., ANG-E2 served as a senior researcher on this task.

4 Method

4.1 Participants

Twenty-four controllers from the NCT's Mulford/Grove and Richmond/Sutro sectors participated in this study. Based on realistic operations, controllers arrived in groups of two participants for the arrival configurations and three for the departure configurations. Each group of participants completed three days of data collection. Simulations were conducted for ten weeks between January and May of 2014 (six weeks for the two arrival configurations and four weeks for the departure configuration).

For the arrival groups, each participant rotated working either Mulford Radar and Grove Radar or Grove Radar and Grove Handoff. For departures, each participant rotated working Radar control, Sutro Radar control, or the CI-1 control position. Each participant completed all test conditions. The participants interacted with each other as well as simulation support staff (see Section 4.2)

4.2 Research Team Roles and Responsibilities

The Co-PIs were responsible for the overall administration of the simulation and analysis. This included conducting the briefings, executing the experiment procedures, supervising data collection, monitoring laboratory operations, administering questionnaires, analyzing the data, and delivering the report. Supporting research staff, including a senior Human Factors Psychologist from the Research Development Human Factors Laboratory (RDHFL), assisted in the planning, development, and execution of the simulation, and assisted in the collection and analysis of data. The research team included ATC SMEs, who created the simulated environment in which the participants operated.

Support personnel from the NIEC and Target Generation Facility (TGF) labs created the simulation scenarios with direction from the research team.

Hardware and software engineers prepared the equipment used in the simulation and were on standby to assist during execution of the study when needed.

4.2.1 Ghost Controller and Ghost Coordinator

During the simulation, two ATC SMEs served as either a ghost controller or a ghost ATC coordinator. The SMEs fulfilled multiple roles, simulating all peripheral and inter-facility coordination, including the controlling authority for the surrounding and overhead airspace. The SMEs gained familiarity with the airspace, scenarios, and ATC and UAS procedures during scenario development and simulation validation sessions. These positions interacted with participants as realistically as possible to simulate NCT operations. The SMEs had the ability to communicate appropriately (via radio frequencies or land lines) for their designated roles.

4.2.2 TGF UAS Pilot

A simulation pilot from the TGF was trained by an experienced Predator/MQ-9 Reaper pilot to fly the UAS and respond in a realistic manner during the simulation. The pilot followed scripted prompts based on realistic responses, interacting with the participants as necessary.

4.2.3 TGF Simulation Pilots

Nine simulation pilots supported the study. To maintain consistency, the same simulation pilots were used throughout the entire process, including training, validation sessions, and simulation runs, without substitutions (however, minimal exceptions were allowed).

All simulation pilots gained familiarity with the airspace, scenarios, activities and procedures during scenario development and simulation validation sessions. Pilots controlled a limited number of individual aircraft by issuing commands from their workstations. The simulation pilots communicated on the appropriate simulated frequencies and issued aircraft commands in response to verbal instructions from air traffic controllers, simulating aircraft, pilot and controller interactions in the field.

4.2.4 Expert Observers

Two ATC SMEs served as expert observers. During simulation runs, the SMEs observed the actions of the controllers, monitored the ATC frequency and manually collected supplemental simulation data using the observer rating forms.

4.3 Assumptions and Constraints

Since UAS are currently restricted as to where and how they are operated, rules and procedures for operating outside Warning Areas or Restricted Airspace were defined. Specific assumptions and limitations were identified and acknowledged as they relate to the conduct and analysis of this exercise, as follows:

- The UAS aircraft used for this study was modeled to simulate realistic aircraft performance characteristics (most similar to a Predator) but was not representative of any specific existing UAS airframe.
- A UAS chase aircraft accompanied all UAS flights, as a standard formation (within 100' vertically, and within 1 NM laterally).
- The UAS chase aircraft was not simulated as a separate target and did not communicate with ATC.
- All join-up and break-up operations by UAS chase aircraft were conducted within the Oakland (OAK) Air Traffic Control Tower's (ATCT) delegated airspace, which was simulated in the ghost sector (the sector controlled by the ghost controller).
- Weather conditions were at or above basic Visual Meteorological Conditions (VMC) for all simulated airspace and airports.

- A simulated Certificate of Authorization was created for this study. It defined the operating limitations and procedures for the UAS while operating within the confines of the NCT airspace.
- All UAS aircraft operated under Instrument Flight Rules (IFR), but in VMC.
- Non-UAS aircraft were simulated under VFR or IFR, and in VMC or IMC, depending on the particular flight operation and scenario.
- Current wake turbulence standards in use at NCT were used in this study. Wake Re-Categorization procedures were not used.
- Visual separation clearances between Runway 30 and Runway 28 were provided by Oakland Tower, which was simulated as part of the ghost sector.
- Software adaptations from the local Standard Terminal Automation Replacement System (STARS) facility were not available for the controllers during the simulations (e.g., leader line offsets, conflict zones, quick look zones, scratchpad shortcuts, etc.).
- VFR operations by the UAS were not permitted.
- ATC was not permitted to give visual clearances to the UAS.
- A UAS-specific Instrument Approach Procedure was developed and required for OAK Runway 30 and Runway 12.
- All adjacent Terminal and En Route sectors were considered de-combined and open, and were represented in the ghost sectors.
- The FLM position was simulated, but provided only advisory/administrative assistance and did not offer procedural/operational suggestions.
- Flight strips were printed for departure aircraft only. No flight strips were printed for overflight or arrival aircraft.

4.4 Equipment and Software

This study used the FAA WJHTC's laboratory hardware and software infrastructure to successfully complete all of the research activities. The research relied on the integration of FAA laboratories, particularly the TGF and NIEC laboratories, as well as external laboratories and partner facilities offered by the WJHTC's R&D domain.

4.4.1 Hardware

Each Air Traffic Control Specialist (ATCS) workstation was equipped with a Barco ISIS 2K x 2K Liquid Crystal Display (LCD), a STARS keyboard and trackball, and an Interim Voice Switch Replacement (IVSR) communications system. The Barco LCD was designed for ATC use and provides the same resolution (2048 x 2048 pixels) and display size as those used in the field (19.83" x 19.83"/28.05" diagonal). Each position was also equipped with a simulated Automated Surface Observing System (ASOS) Controller Equipment-Information Display System (ACE-IDS) overhead display. The functionality was limited, but it provided participants with the ability to view information such as airport weather and status, facility operating procedures, maps, Letters of Agreement (LOAs), published arrival and departure procedures, and

UAS-specific procedures, including the full text of the COA. An additional Coordinator (CI-1) position was sometimes added between two STARS positions depending on the sector configuration. Each position was also equipped with an interphone and frequency monitor capability. An UER512 Thermal Flight Progress Strip (FPS) printer was located directly in front of the CI-1 position. Tablets were also present in front of each position to provide the capability to measure subjective workload. See Figure 4-1 for an example of the ATCS workstations.

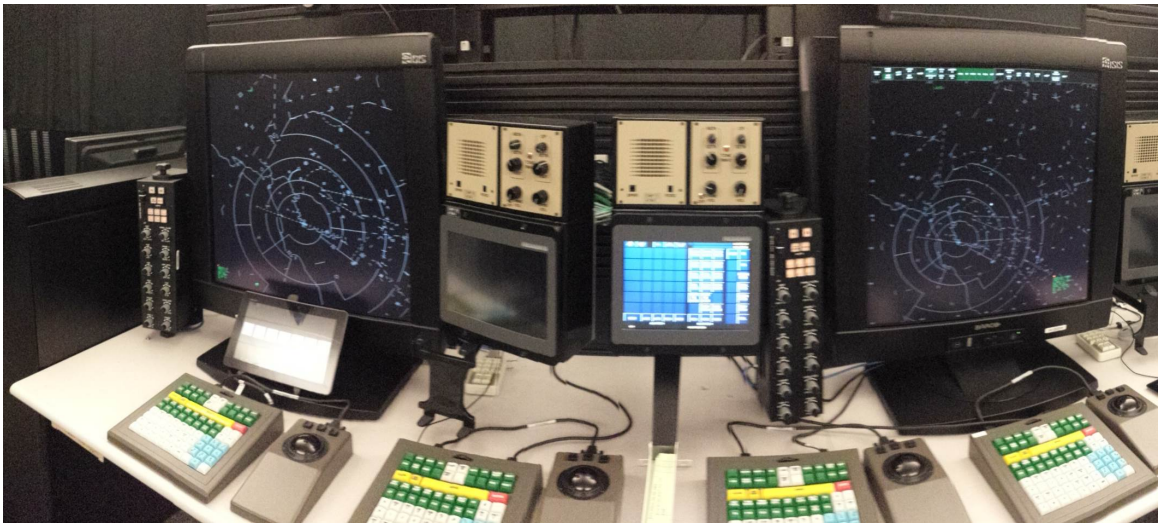

Figure 4-1 ATCS Workstations

SMEs used separate workstations, away from the simulated STARS positions, to simulate adjacent sectors and facilities. These additional SME positions were referred to as ghost controller and/or ghost coordinators.

The ghost coordinator positions were equipped with the ECO/Java Plan View Display (JPVD) capability and STARS interface. The ghost coordinators also had interphone capability with the simulated STARS positions and with the TGF coordinator. The ghost coordinators were able to monitor the frequencies and "force flight strips" to the STARS printer if necessary. The STARS and ghost coordinator positions were driven by the TGF and Distributed Environment for Simulation, Rapid Engineering and Experimentation (DESIREE) systems. Figure 4-2 shows the NIEC Laboratory layout during the simulation.

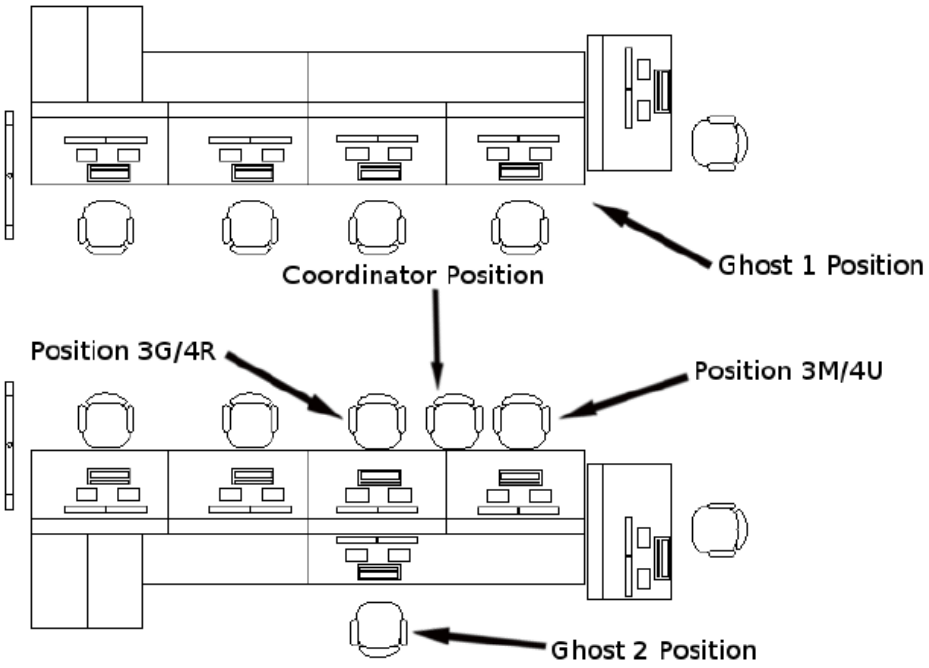

Figure 4-2 NIEC Laboratory Layout

4.4.2 Software

The simulation used the DESIREE system along with the TGF. DESIREE consists of a series of interchangeable human-machine interfaces. It has the capability to emulate multiple ATC platforms and displays. Its purpose is to enable researchers to modify or add information and functionality to a variety of current ATC environments to allow for the evaluation of new concepts and procedures. DESIREE receives input from TGF that allows it to present information on a radar display (e.g., STARS, Display System Replacement (DSR), and En Route Automation Modernization (ERAM)), including radar tracks, data blocks, and sector maps. It also allows air traffic controllers to perform the typical functions that they would perform in the appropriate ATC operational environment (e.g., performing handoffs, entering data into the host computer). DESIREE can also emulate ghost sector operations by providing automation to control these unstaffed sectors. When needed, this automation can communicate with the TGF to act as a simulation pilot for the aircraft. DESIREE has data collection capabilities and can collect information on all air traffic controller entries made during a simulation run. For this study, the DESIREE system supplied the STARS interface and simulated STARS functionality.

The TGF simulated manned and unmanned aircraft operating in a designated airspace. TGF is a software tool developed by WJHTC engineers to simulate air and ground traffic throughout all phases of flight. The TGF capability enables researchers to investigate new aviation related systems, procedures, and concepts without having to fly actual aircraft.

TGF uses preset flight plans and dynamic flight models to generate simulated surveillance tracks. The TGF algorithms control aircraft maneuvers so that they represent realistic climb, descent, and turn rates. In addition, TGF has the capability to record information about aircraft trajectories, proximity, and other relevant data, which researchers can then use in subsequent analyses.

For this study, the TGF provided aircraft performance models, generated aircraft tracks based on predefined flight plans, and managed the ghost coordinator and simulation pilot workstations. The TGF also created a UAS model based on realistic aircraft performance characteristics and UAS model data (most similar to a Predator). Both DESIREE and TGF provided data collection capability (e.g., number and type of controller entries on STARS; number of aircraft maneuvers such as heading, speed, and altitude changes; and time and distance flown within each sector).

4.4.3 Workload Assessment Keypad

Controllers used the Workload Assessment Keypad (WAK) devices to provide workload ratings using the Air Traffic Workload Input Technique (ATWIT). ATWIT is an unobtrusive and reliable technique for collecting controller workload ratings as they work traffic in a simulation (Stein, 1985; Stein, 1991). The WAK consists of a touch panel display presented on an iPad tablet with seven buttons labeled from “1” to “7.” The tablet controls the device and records workload ratings. The system was programmable, allowing researchers to select the timing parameters for the study. The system prompts controllers for workload ratings at a selected time interval by emitting several beeps and illuminating the keypad buttons. Controllers provide workload ratings by pressing one of the seven buttons, where 1 indicates very low workload and 7 indicates very high workload. If controllers do not respond before the timeout period, the system records a code indicating there was no response. A workload rating interval of four minutes was chosen for this study, and the timeout period was set at twenty seconds. Figure 4-3 depicts the iPad on which the workload was assessed during simulation, located just below the monitor.

Figure 4-3 Workload Assessment Keypad

4.4.4 Audio-Video Recording System

The NIEC's audio-video recording system was used to record controller voice communications and actions during the simulation. A microphone was situated near each controller position to record controller-to-pilot communications and conversations with the controllers operating adjacent sectors. An overhead video camera was also situated above each controller position to record controller upper body and arm actions. The audio-video recording served as a record of the simulation that the researchers reviewed when necessary.

4.4.5 Communications

A simulated communication environment permitted realistic air-ground and ground-ground voice communications between the NCT controllers, simulation pilots, and ghost controllers. The communications setup allowed for selection and use of the primary NCT sector and surrounding ATCT and ARTCC facilities (San Francisco (SFO), Oakland (OAK), Hayward (HWD), Livermore (LVK), and Oakland (ZOA)) using discrete frequencies in the simulated operational environment. Land line communications were also available to provide interconnectivity between the primary NCT sectors, ghost sectors, and surrounding facilities as appropriate.

In addition, a dedicated Emergency Communications telephone line was established to provide a direct fail-safe method of communication between the TGF UAS Simulation pilot workstation, and the staffed NCT FLM position in the control room. Table 4-1 describes the sector combinations and frequencies.

Note: Airspace Configurations are explained in Section 4.6.

Table 4-1 Sector Combinations and Frequencies

Sector Combinations & Frequencies			
Facility & Sector	**Airspace Configuration**	**Combined With/Composition:**	**Frequencies MegaHertz (MHz):**
NCT Sutro	2	None	135.1
NCT Richmond	2	Diablo	120.9, 127.0
NCT CI-1	2	None	Receive (Rx) only: 135.1, 120.9, 127.0
NCT Grove	1 & 3	None	125.35
NCT Mulford	3	None	124.4
NCT Grove Handoff	1	None	Rx only: 125.35
Ghost 1	1	ZOA35, ZOA40, ZOA41, Diablo, Richmond, Sutro, Travis Radar Approach Control (RAPCON), Tracy, CI-1	134.15, 127.8, 125.85, 127.0, 120.9, 135.1, 119.9, 123.85
	2	ZOA35, ZOA40, ZOA41, Travis RAPCON, Fairfield, Quake, Grove, Mulford	134.15, 127.8, 125.85, 119.9, 124.32, 127.97, 125.35, 124.4
	3	Richmond, Diablo, Niles, Tracy, CI-1	120.9, 127.0, 134.5, 123.85
Ghost 2	1	SFO, OAK-2, OAK-1, Boulder, Niles, Woodside, Foster, Sunol	120.5, 118.3, 127.2, 133.95, 134.5, 135.65, 120.35, 124.8
	2	Boulder, Foster, Niles, Woodside, SFO, OAK-1, OAK-2	133.95, 120.35, 134.5, 135.65, 120.5, 127.2, 118.3
	3	Boulder, Foster, Sunol, Toga, SFO, OAK-1, OAK-2, HWD, LVK, PAO, SQL	133.95, 120.35, 124.8, 121.3, 120.5, 118.3, 127.2, 120.2, 118.1, 118.6, 119.0
NCT FLM	1, 2, 3	N/A	Rx only: 135.1, 120.9, 127.0, 125.35, 124.4
TGF Pilots (Manned Aircraft)	1, 2, 3	N/A	All
TGF UAS Pilot	1, 2, 3	N/A	All

4.4.5.1 Air-to-Ground Communication

Communications panels and headsets were present at workstations for each ATCS and each TGF simulator position. The ATC sector positions were configured as single operator positions, which varied by position name and discrete Very High Frequency (VHF) channel, dependent upon one of three airspace configurations developed for the study. All Air-to-Ground (A/G) communications were recorded and time-stamped.

A simulated communication environment permitted realistic A/G voice communications between the pilot simulation stations located in the TGF and the ATCS in the NIEC Lab. The simulated communication environment was used for all A/G voice communications during the study. This environment allowed the selection, interconnection, and activation of frequencies assigned to the controller, ghost, and TGF pilot positions by the simulation pilots in the TGF for two-way radio communications, as shown in Figure 4-4.

The TGF simulation pilots used standard Push-to-Talk (PTT) ATC headsets plugged into the voice communications interface within the TGF pilot simulation station. Each TGF pilot simulation station's voice communications interface was directly connected to the Laboratory Combined Control and Communications System (LCCCS). The LCCCS is an automated switching communications system that interconnected various FAA voice switching systems to the TGF simulated pilots, live radios, and voice recorders. The LCCCS provided automated switching between the TGF pilot simulation stations and the controllers' designated frequencies just as any of the operational NAS voice switches such as the Voice Switching and Control System (VSCS), Rapid Deployment Voice Switch (RDVS), IVSR, Enhanced Terminal Voice Switch (ETVS), and Small Tower Voice Switch (STVS) would. Within the LCCCS, each frequency was assigned a unique physical port where the LCCCS placed the corresponding PTT signal similar to the Radio Communications Equipment (RCE) for keying the radios to transmit in the operational NAS. Each of these LCCCS ports was connected to a corresponding radio card within the IVSR switch mapped to the same frequency assignment via a six-wire, 600-Ohm, twisted-pair cable. The IVSR switch then mapped each assigned frequency via the E1 interface to the corresponding IVSR controller position completing the A/G communications pathway.

The IVSR is a fully digital voice communication switching system supporting up to eighty positions. The IVSR comprises a fully redundant duplicated core switch providing highly reliable and fault tolerant voice communications at FAA towers and TRACON facilities. Voice and signaling data are transferred via redundant digital high-speed highways. The core system hardware of the IVSR comprises redundant circuit boards and modules to ensure no single fault interrupts ATC communications.

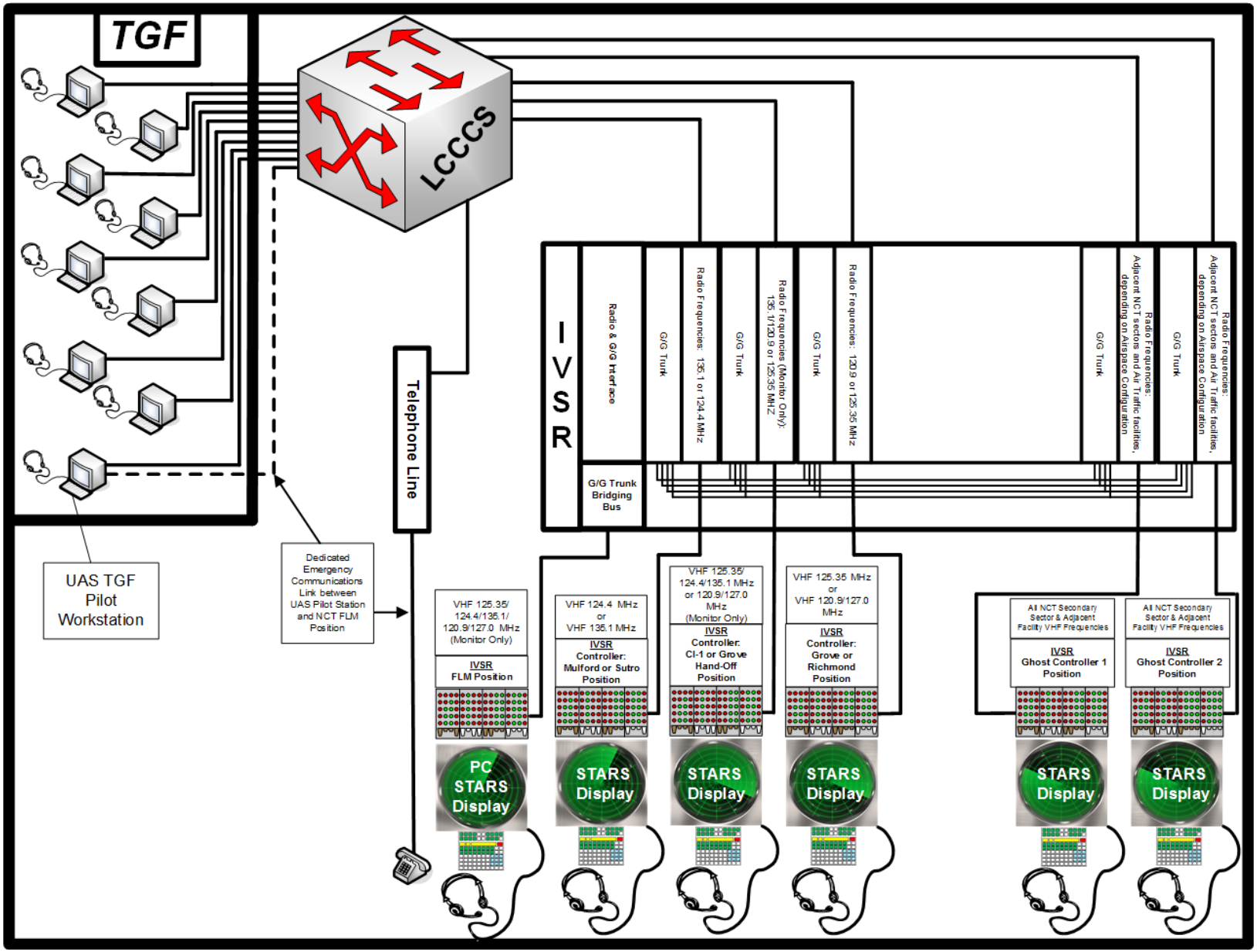

Figure 4-4 Simulated Communication Environment

4.4.5.2 Ground-to-Ground Communication

Ground-to-Ground (G/G) communications between the controllers and ghost controllers was provided by the IVSR via the G/G trunk cards, which plug into the G/G trunk bridging bus within the IVSR. The IVSR G/G system was reconfigured to match real-world sector land lines and frequencies for each sector, dependent upon one of three airspace configurations developed for the study. All G/G communications were recorded and time-stamped.

An additional dedicated emergency land line was established to provide an alternative method of communication between the ATC participants and specific UAS TGF simulation pilot workstations. The line was connected via standard telephone lines to the FLM position in the NIEC lab adjacent to the ATC controller positions. The FLM would manually relay communications from the PIC to the appropriate controller position.

4.5 Materials

4.5.1 Informed Consent Form

Each participant read and signed an informed consent form before beginning the experiment (see Appendix A). Informed consent forms describe the study, the foreseeable risks, the rights and responsibilities of the participants, and include a statement that participation in the study is voluntary. All the information that participants provide, including Personally Identifiable Information (PII), is protected from release except as may be required by statute. Signing the form indicates the participants' consent to participate and their understanding of their rights as participants in the study.

4.5.2 Biographical Questionnaire

Each participant completed a biographical questionnaire before beginning the experiment. The purpose of the questionnaire is to collect general descriptive information about the participants, including gender, age, and level of ATC experience (see Appendix B).

4.5.3 Post-Scenario Questionnaire

The participants completed a post-scenario questionnaire after each scenario. The purpose of this questionnaire is to collect data regarding the controller's experience in the traffic scenario just completed. The controllers provided ratings about their performance, workload, SA, and the events that occurred in the scenarios. The questionnaire included six questions related to the six dimensions of the NASA-Task Load Index (TLX) rating scale (Hart & Staveland, 1988). NASA-TLX is a multi-dimensional scale designed to obtain subjective workload estimates of mental demand, physical demand, temporal demand, effort, and frustration (rated on a scale of 1-10, "1" representing "extremely low" and "10" representing "extremely high"), as well as their subjective assessment of performance (rated on a scale of 1-10, "1" representing "very poor" and "10" representing "very good"). The questionnaire also included open-ended questions and allowed the controllers to comment about anything they experienced during the scenario that they considered relevant to the study (see Appendix C).

4.5.4 Post-Experiment Questionnaire

The participants also completed a Post-Experiment Questionnaire after performing all the traffic scenarios in the study. The purpose of this questionnaire is to collect data regarding the controller's experience in the entire experiment. The controllers provided ratings about the realism of the simulation, including the airspace, traffic scenarios, and ATC equipment. This questionnaire included open-ended questions and allowed the controllers to comment about anything they experienced during the entire experiment that they considered relevant to the study (see Appendix D).

4.5.5 Observer Rating Form

After each test scenario, SMEs from the research team used the Observer Rating Form to provide performance ratings for each participant in the study. Research psychologists and SMEs at the FAA WJHTC developed the form to evaluate new ATC concepts and procedures by observing controllers in HITL simulations (Sollenberger, Stein, & Gromelski, 1997; Vardaman & Stein, 1998). The form consisted of several rating scales designed to assess different aspects of ATC performance, such as resolving aircraft conflicts, sequencing aircraft, prioritizing tasks, communicating effectively, and maintaining SA (see Appendix E).

4.5.6 Front Line Manager Form

The research personnel acting as the FLM in the simulation completed the FLM Form after each scenario. The purpose of this form was to record data and comments about the communications between the participant and the FLM (see Appendix F).

4.6 Airspace

The NCT was selected as the representative airspace environment for this study. NCT airspace encompasses more than 21,000 square miles and covers a major portion of central California, extending from Marysville to the north, Merced to the south, and bordered to the west by the Pacific Ocean, and the Sierra Nevada foothills to the east. The general vertical limits of NCT airspace extend from the surface up to and including Flight Level 190, with ZOA as the controlling ATC authority for most of the surrounding and overlying airspace. Within NCT's control jurisdiction are several high-volume terminal areas including airports in the San Francisco Bay Area such as SFO, OAK and San Jose International (SJC). NCT also encompasses the terminal areas that include the Sacramento International, Stockton Metropolitan, Reno/Tahoe International, and Monterey Peninsula airports.

In total, the NCT serves over eighteen airports with operating control towers (civilian, military, and joint use) and numerous other smaller, uncontrolled airports that primarily serve general aviation.

Specific NCT sectors selected for this study include:

- Richmond: Primarily a departure sector for the SFO and OAK airports for flights with destinations to the north and east.

- Sutro: Also a primary departure sector for the SFO and OAK airports, for flights with destinations to the west (oceanic) and south.
- Grove: Primarily an arrival sector for the OAK airport that includes Runways 28 Left/Right (L/R), and Runways 12, 10R/L, during East Plan configurations.
- Mulford: During West Plan configurations, Mulford serves primarily as an arrival sector for the OAK airport "South Field" that includes Runway 30, the main commercial runway. During West Plan configurations, Mulford also provides arrival services to the HWD airport.

The NCT sectors were simulated in one of three configurations:

1. Grove and Grove Handoff during San Francisco Bay East Plan
2. Richmond and Sutro sectors during San Francisco Bay West Plan.
3. Mulford and Grove sectors during San Francisco Bay West Plan.

The "San Francisco Bay East/West Plan" refers to traffic flow configurations at the NCT that are dependent upon prevailing weather conditions and active runways at the primary San Francisco area airports: SFO, OAK, and SJC.

These sectors were selected because of the complex and diverse traffic flows, parallel runway operations, and moderate-to-heavy airport demands. They offered the research team flexibility in developing several contingency options with realistic scenarios.

Although all of the simulated flights either initiated or terminated within surrounding ATC facilities and airspace such as airport Class C/D surface areas, adjacent RAPCONs, or ZOA, the focus of this study was operations within the selected NCT sectors.

NCT is responsible for providing air traffic services within the defined airspace for each sector. These services are in accordance with FAA JO 7110.65V, including current notices, NCT Standard Operating Procedures NCT Order 7110.6V, current Letters of Agreement, and all other Federal Rules and Regulations. For this study, one radar controller provided services for each of the simulated NCT sectors, with coordinator positions where required. ATC services outside of the jurisdiction of the simulated sector airspace, including all adjacent NCT sectors and ATC facilities, were simulated by the ghost controller and ghost coordinator positions.

4.7 Traffic Scenarios

Two training scenarios and seventeen data collection scenarios were developed for this simulation. The scenarios were split by configuration: four scenarios were simulated in Configuration 1, eight in Configuration 2, and five in Configuration 3. One baseline scenario was created for each of the configurations (three baselines total). Baseline scenarios did not include any UAS. For the remaining fourteen scenarios, a UAS emulating realistic performance characteristics similar to a Predator was included and specific contingency events were simulated, such as lost link, lost communication, fly-away, emergency divert, engine failure, lost link with multiple UAS, and flight termination.

All baseline scenarios were intentionally designed not to include any UAS. This was based on SME subjective assessments that having a UAS without a contingency would be no different than a manned aircraft. (These assessments were established via a cognitive walk-through session that was conducted with three ATC SMEs and one UAS SME.) SMEs stated they would treat a UAS without a contingency as they would any manned aircraft. (Note: Data to confirm these assumptions is provided in Appendix Q.) Moreover, based on the scope of the research charter as well as budget/schedule limitations, researchers focused the study on UAS contingency operations.

All scenarios lasted thirty minutes and required coordination with ATC in attempting to resolve the contingency situation, with the exception of the baselines. All scenarios included normal, realistic traffic interactions. All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start time was 0830 local, and VMC prevailed throughout the scenarios. Winds were calm and the primary active runways at OAK were either 30/28L/28R or 12/10L/10R, dependent upon airspace configuration.

Manned Aircraft: Manned aircraft were introduced to simulate normal traffic flows within the airspace. Operations included both military and civilian departures, arrivals, over-flights, and VFR aircraft. Although the manned aircraft followed preprogrammed and scripted flight plans, each flight was under the control of a TGF simulation pilot. The pilot retained full control over the aircraft and responded to ATC instructions accordingly.

Numerous additional VFR targets using a 1200 transponder code were introduced to simulate routine operations during a normal "VFR day" environment. The 1200-code VFR targets followed preprogrammed routes and did not communicate with ATC. TGF simulation pilots did not have the ability to control these aircraft.

Unmanned Aircraft Systems: All non-baseline scenarios included one or two UAS.

Airspace Configurations: Three unique airspace configurations were developed for the study based upon arrival or departure flows and active runways at SFO and OAK, and specific sectors of interest.

A summary of the scenarios is presented in Table 4-2. Detailed descriptions of the scenarios by configuration follow.

Table 4-2 Scenario Summary

UAS Event Type	Airspace Configuration	Primary Sectors	UAS Event Description	UAS Call-Signs	UAS Arrival or Departure Fix	Notes
Baseline	1 (OAK Runway 12 Arrival Scenario)	Grove	No Event	N/A	N/A	N/A
Fly-away	1 (OAK Runway 12 Arrival Scenario)	Grove	UAS Fly-away Due to Global Positioning System (GPS) Failure	CUTTR12 CUTTR16	SGD	Lost link and fly-away after intercepting final approach course. UAS simultaneously proceeds to FARRA and climbs to 10,000'
Lost Link	1 (OAK Runway 12 Arrival Scenario)	Grove	Lost Link During Approach Phase	CUTTR13 CUTTR57	SGD	Lost link On final approach between ALCAT & PLAZA
Lost Comm	1 (OAK Runway 12 Arrival Scenario)	Grove	UAS loses A/G Communication. Retains Command & Control of Aircraft	CUTTR14 CUTTR62	SALAD	Loss of communications after first check-in. Continue to OAK
Baseline	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	No Event	N/A	N/A	N/A
Lost Link-Cruise	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	Lost Link During Initial Cruise Phase	CUTTR22 CUTTR88 CUTTR47	FARRA	Lost link after UAS is established southwest-bound, before crossing the SFO PYE arrival flow

UAS Event Type	Airspace Configuration	Primary Sectors	UAS Event Description	UAS Call-Signs	UAS Arrival or Departure Fix	Notes
Flight Termination	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	Lost Link and Flight Termination	CUTTR23 CUTTR70 CUTTR66	ECA	Lost link near SALAD intersection. UAS proceeds to the Lost-link Loiter Point (LLP)/Flight Termination Point (FTP)
Lost Comm	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	UAS loses A/G Transmitter on ATC Frequency. UAS Pilot Retains A/G Receiver and Command/Control of Aircraft	CUTTR24 CUTTR62 CUTTR54	NUEVO	Loss of communication receiver immediately after departure. Request Return to Base (RTB) OAK (Loss of transmitter only)
Fly-away	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	UAS Fly-away due to GPS Failure	CUTTR25 CUTTR77 CUTTR97	CCR	Lost link/fly-away after UAS is established northeast-bound. UAS reverses course
Engine Failure	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	Engine Failure Resulting in Flight Termination	CUTTR26 CUTTR76 CUTTR48	NUEVO	Progressive engine failure as UAS proceeds south-bound. Advise ATC of engine issue. Request RTB OAK Runway 30. Total engine failure and eventual flight termination
Lost Link Departure	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	Lost Link on Departure	CUTTR27 CUTTR37 CUTTR05	SGD	Lost link immediately after departure. Reacquire link after reaching LLP. UAS request: RTB OAK
Lost Link-Multiple	2 (OAK Runway 30 Departure Scenario)	Sutro Richmond	Lost Link with Multiple (2) UAS	CUTTR28/29 CUTTR53/19 CUTTR94/44	SGD/ECA	UAS #1 Lost link at ZOA41/NCT boundary. UAS #2 Lost link after departure.

UAS Event Type	Airspace Configuration	Primary Sectors	UAS Event Description	UAS Call-Signs	UAS Arrival or Departure Fix	Notes
Baseline	3 (OAK Runway 30 Arrival Scenario)	Mulford Grove	No Event	N/A	N/A	N/A
Lost Comm	3 (OAK Runway 30 Arrival Scenario)	Mulford Grove	UAS loses A/G Communication. Retains Command & Control of Aircraft	CUTTR32 CUTTR51	SGD	Lost communications after first check-in on north downwind; Continue RTB OAK
Fly-away	3 (OAK Runway 30 Arrival Scenario)	Mulford Grove	UAS Fly-away due to GPS Failure	CUTTR33 CUTTR70	LOCKE	Lost link & fly-away before intercepting final approach course. UAS continues on last assigned heading and altitude.
Emergency Divert	3 (OAK Runway 30 Arrival Scenario)	Mulford Grove	Runway Closure and UAS Divert	CUTTR34 CUTTR38	SGD	Runway 30 CLOSES due to disabled manned aircraft UAS requests a change of destination to Edwards Air Force Base (EDW) via ALTAM ECA CZQ KEDW, FL190
Lost Link	3 (OAK Runway 30 Arrival Scenario)	Mulford Grove	Lost Link During Approach Phase	CUTTR35/47	PXN	Lost link on final approach course, before communication transfer to OAK ATCT

4.7.1 Airspace Configuration 1 and Detailed Traffic Scenarios

OAK runways 12 and 10 were in an arrival configuration with SFO and OAK airports operating "East Plan." East Plan refers to the primary runways in use at the SFO and OAK airports. During East Plan operations, OAK's primary arrival/departure runways were 12, 10R, and 10L. SFO's primary arrival runways were 19L and 19R, and departures were assigned 10L and 10R. The NCT Grove position was the sector of interest and served as the primary OAK arrival position for all runways under this configuration. Additionally, the Grove Handoff position was staffed with a NCT ATCS to assist the Grove controller as needed. All UAS traffic during Configuration 1 was initially injected into the scenarios as arrivals to OAK Runway 12.

Per the COA developed for this study, the UAS Lost-link Loiter Point (LLP)/Flight Termination Point (FTP), was established over a geographical landmark, Mt. Diablo, approximately 17 NM northeast of OAK. Although within the lateral confines of Grove's sector, the COA-mandated lost link holding altitude of 5,000' was above the vertical limit of Grove's airspace, and within an overlying NCT sector that handles SFO final approaches. See Figure 4-5 for the Grove sector diagram for Configuration 1. Figure 4-6 depicts the airspace with six manned aircraft tracks for arrival and departure routes (in yellow) in the baseline scenario.

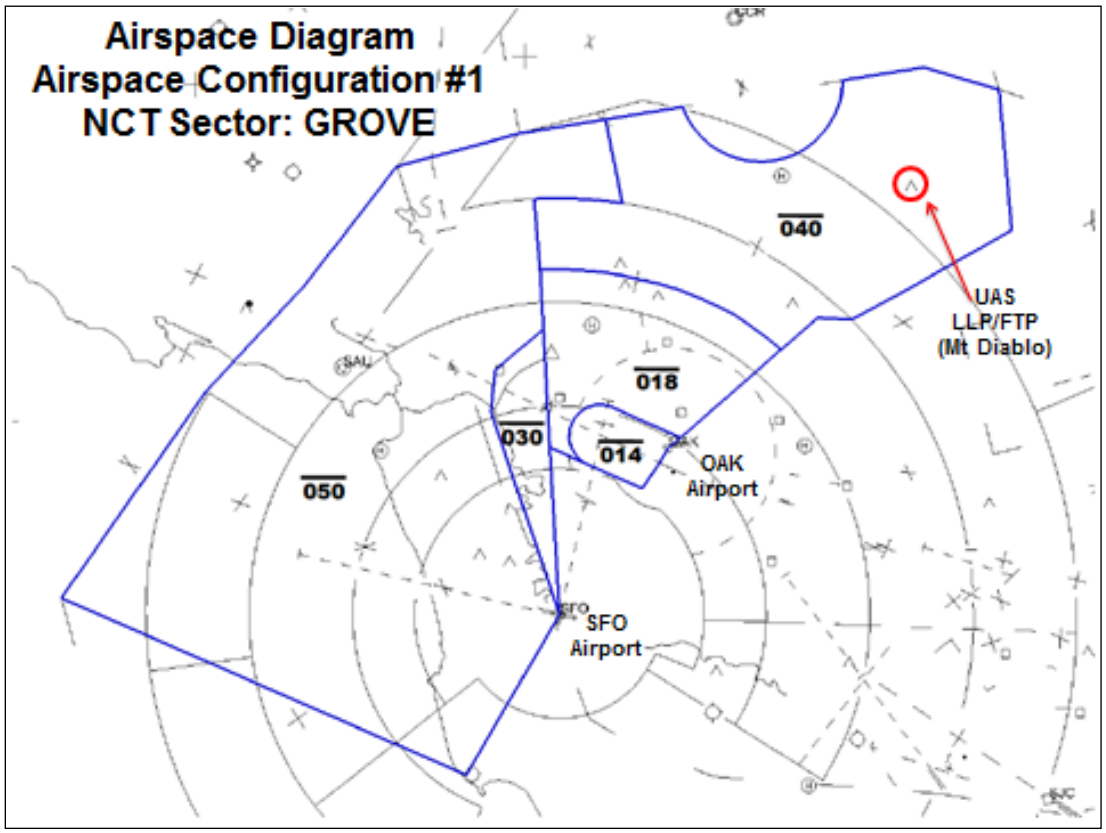

Figure 4-5 Configuration 1, Grove Sector Diagram

Note: Unless otherwise stated, altitudes are reference MSL (above Mean Sea Level)

No UAS operations were injected into this scenario and all aircraft were manned, following standard arrival and departure routes.

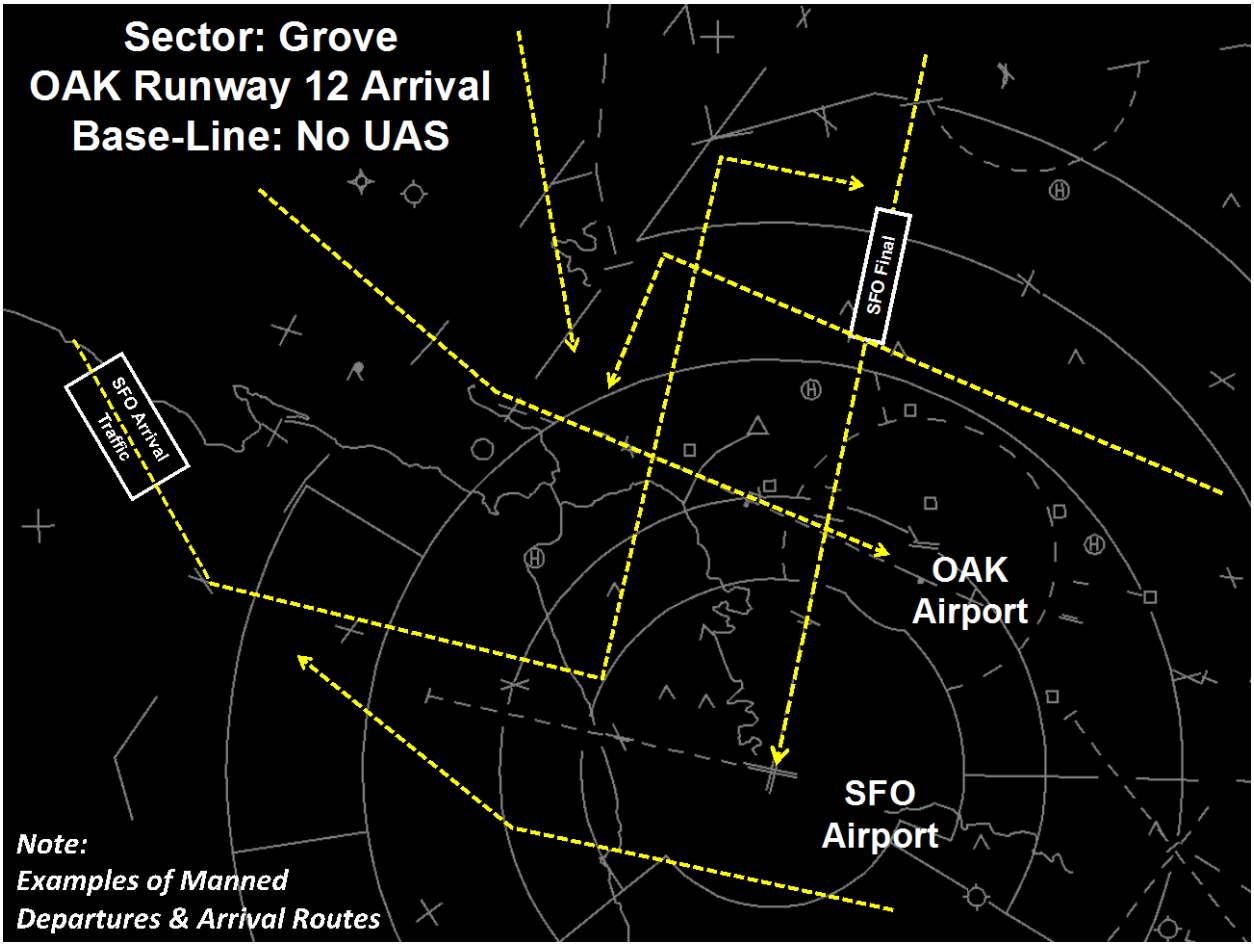

Figure 4-6 Configuration 1, Baseline

For the fly-away scenario depicted in Figure 4-7, the UAS was an arrival from the northwest, handed off to the Grove sector from ZOA. Just prior to intercepting the Runway 12 final approach course, the UAS experienced a lost link and the pilot notified ATC of the aircraft status via the emergency land line. The UAS did not comply with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'). The UAS experienced a fly-away condition, turned the opposite direction, climbed to 10,000' and proceeded Direct FARRA intersection, approximately 30 NM west of Oakland.

Due to the nature of the lost link, the UAS pilot responded to all queries by ATC, and reported the inability to command any maneuver and expectation that the UAS would follow the lost link procedure.

During this configuration, the upper altitude limit of Grove's airspace for the UAS Fly-away route is only 5,000', and the unexpected climb to 10,000' placed the UAS in conflict with the SFO arrival traffic, worked by an overlying NCT sector at 6,000' and above.

This scenario was designed to examine ATC's ability to adapt to a UAS that is proceeding contrary to the expected procedure in complex airspace, as well as any effects on adjacent sectors.

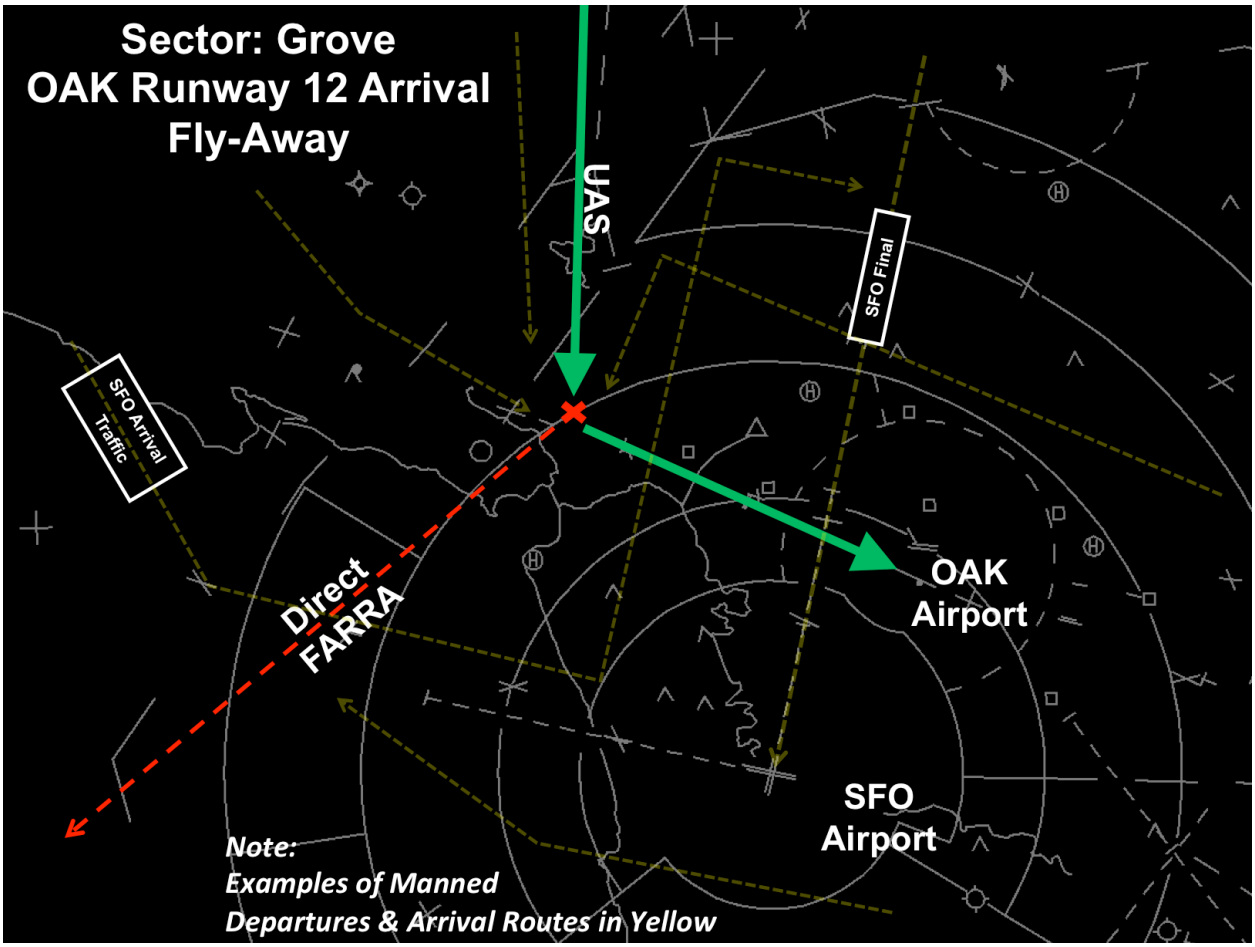

Figure 4-7 Configuration 1, Fly-away

For the lost-link scenario depicted in Figure 4-8, the UAS was an arrival from the northwest, handed off to the Grove sector from ZOA. The UAS experienced a lost link after intercepting the Runway 12 final approach course, prior to communications transfer from Grove to Oakland tower. The UAS pilot informed ATC of the lost link via the emergency land line and informed ATC of the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000').

With this airspace configuration, the final approach course for OAK Runway 12 crossed underneath the SFO Runway 19L/R final approach courses, which were controlled by overlying NCT sectors. Aircraft on final approach to OAK must comply with all published and ATC assigned crossing restrictions while on the approach, to ensure adequate separation from the SFO arrival traffic. The unexpected UAS lost link violated protected approach airspace and placed the aircraft in direct conflict with the SFO arrival traffic.

This scenario was intended to examine the effects of a single lost-link procedure for multiple runway configurations and the effects on operations in adjacent airspace.

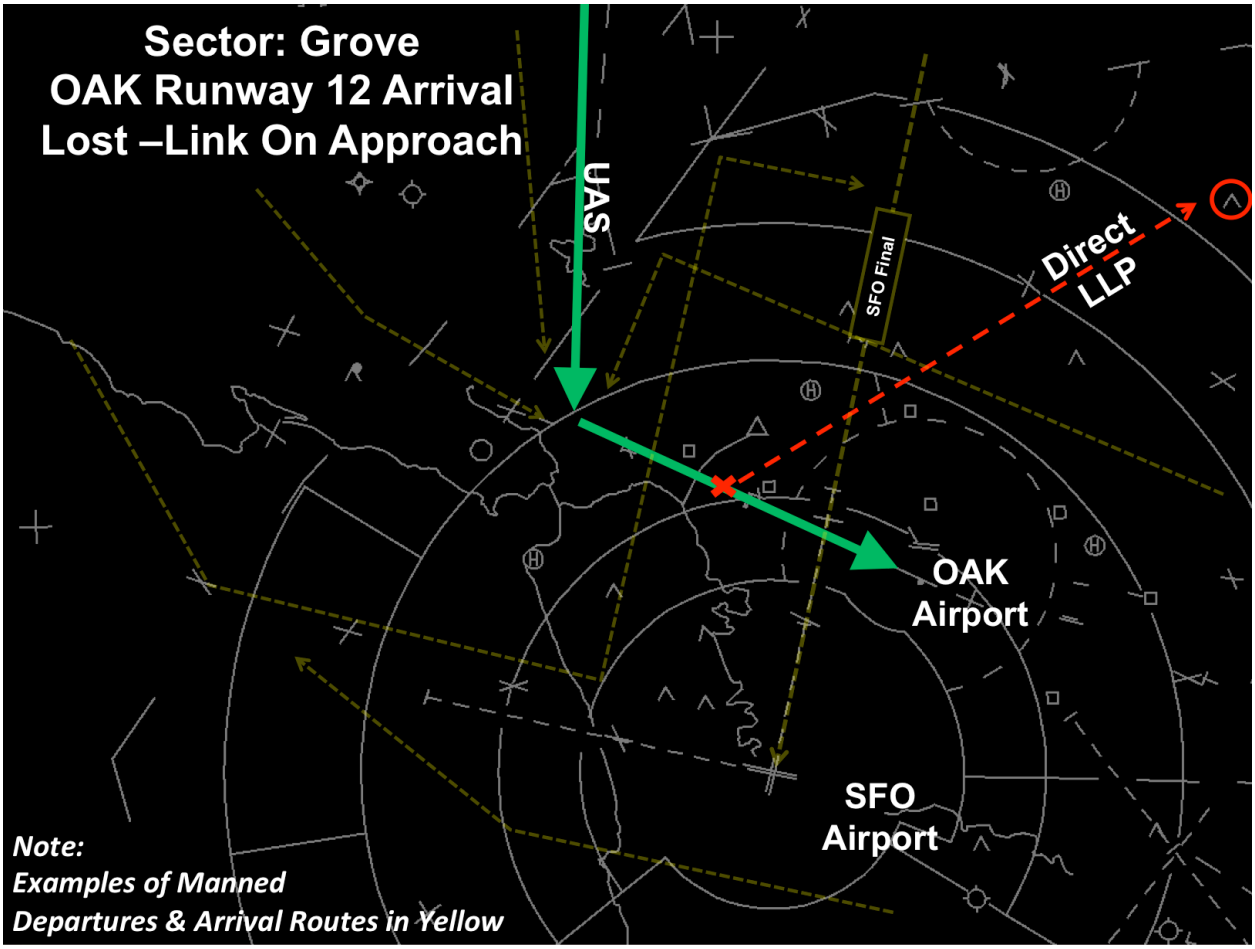

Figure 4-8 Configuration 1, Lost Link

In the lost communications scenario shown in Figure 4-9, the UAS was an arrival from the east, handed off to the Grove sector from an adjacent NCT sector. After initial radio check-in with ATC, the UAS pilot experienced a loss of two-way radio communications with ATC. After approximately one minute, the UAS pilot advised ATC of the status of the aircraft, via the UAS/ATC emergency land line, and awaited instructions from ATC. There was no lost link associated with this failure and the aircraft remained responsive to UAS pilot command & control.

This scenario was designed to examine how ATC would respond to a UAS pilot experiencing a loss of two-way radio communications, and if the actions would differ from established procedures for manned aircraft. The scenario was also designed to examine the effect on ATC of having an emergency communications land line available during UAS operations with compromised radio communications.

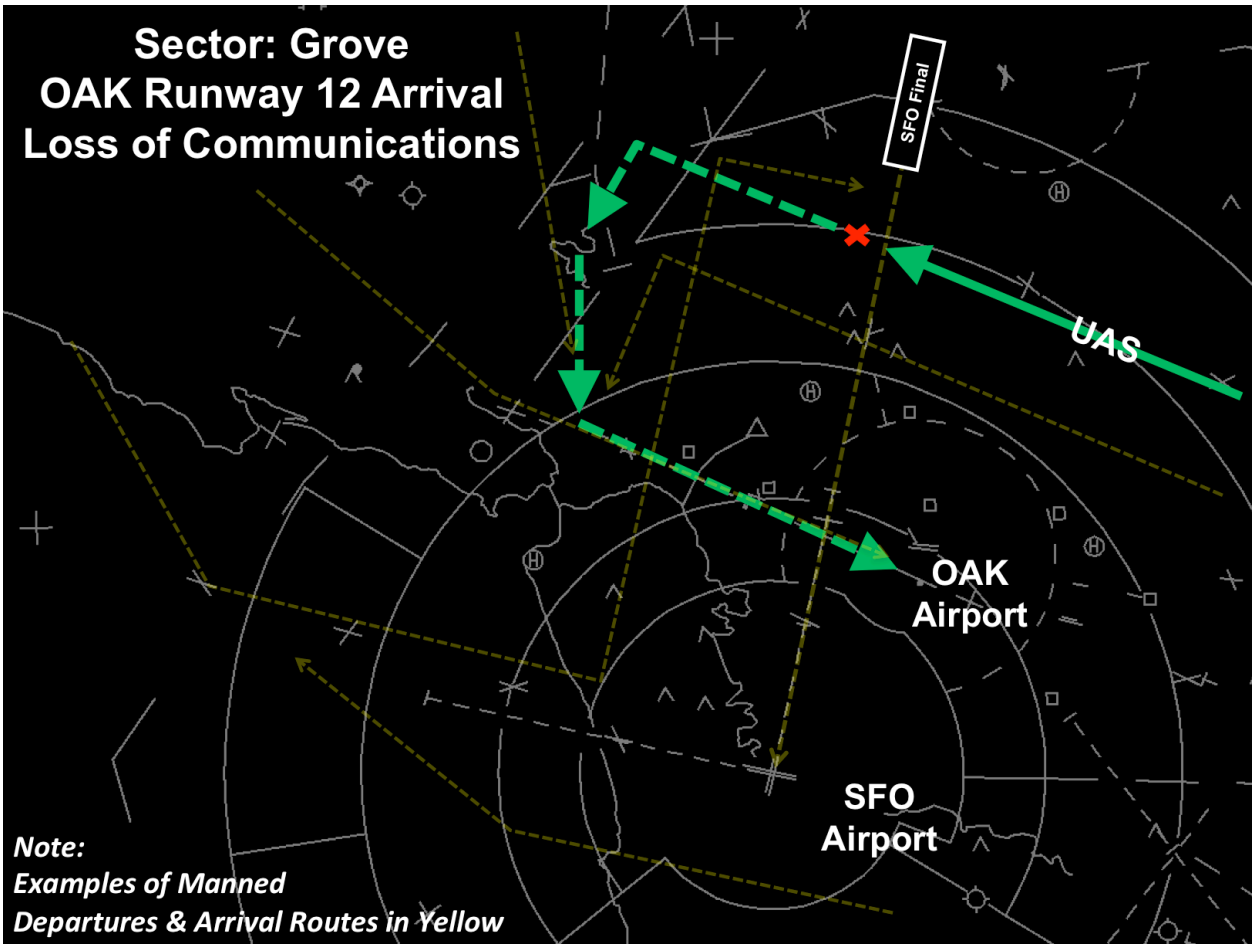

Figure 4-9 Configuration 1, Lost Comm

4.7.2 Airspace Configuration 2 and Detailed Traffic Scenarios

OAK and SFO departures were configured for "West Plan" operations. "West Plan" refers to the primary runways in use at SFO and OAK. During West Plan operations, Oakland's primary arrival/departure runways were 30, 28R, and 28L. San Francisco's primary runways for arrivals were 28L and 28R, with departures from runways 1L and 1R, 28L and 28R. The NCT Sutro and Richmond sectors served as the primary SFO and OAK departure positions during West Plan operations and were the sectors of interest for this configuration. Individual aircraft sector/frequency assignment was based on the flight plan for each departure. Typically, all OAK/SFO departures routed to the northwest, then clockwise through east, and were under the control jurisdiction of Richmond. OAK/SFO departures with flight plan routes to the west were assigned to Sutro. These were routed west, then counterclockwise to south. Additionally, the CI-1 coordinator position was staffed with NTC ATCS for each of the Configuration 2 scenarios. All scenarios involving UAS during Configuration 2 were scripted as departures from Oakland Runway 30.

Configuration 2 includes an additional NCT sector, Diablo, which underlies the Richmond sector from 2,000'- 5,000'. Diablo sector's primary function is to handle IFR propeller traffic

departing OAK runways 28L/28R. The Diablo sector also provides Class C services to VFR aircraft operating to/from OAK, and additional VFR services to aircraft in the general area north and west of SFO and OAK. Except during moderate-to-high traffic periods, Diablo is normally combined with Richmond, and this combined sector arrangement was used for all scenarios in Configuration 2.

Per the COA developed for this study, the UAS LLP was established over a geographical landmark, Mt. Diablo, approximately 17 NM northeast of OAK. Together with the COA-mandated lost-link holding altitude of 5,000', the LLP was within the vertical and lateral confines of the combined Richmond/Diablo airspace.

The design of the airspace and the varied departure flows require frequent coordination between the Richmond and Sutro controllers, and the assistance of the CI-1 coordinator. The condensed traffic flows, airspace constrictions, and geographical obstacles result in operations and events that can affect both sectors simultaneously. The Richmond, Diablo, and Sutro sector diagrams for Configuration 2 are depicted in Figure 4-10, Figure 4-11, and Figure 4-12, respectively.

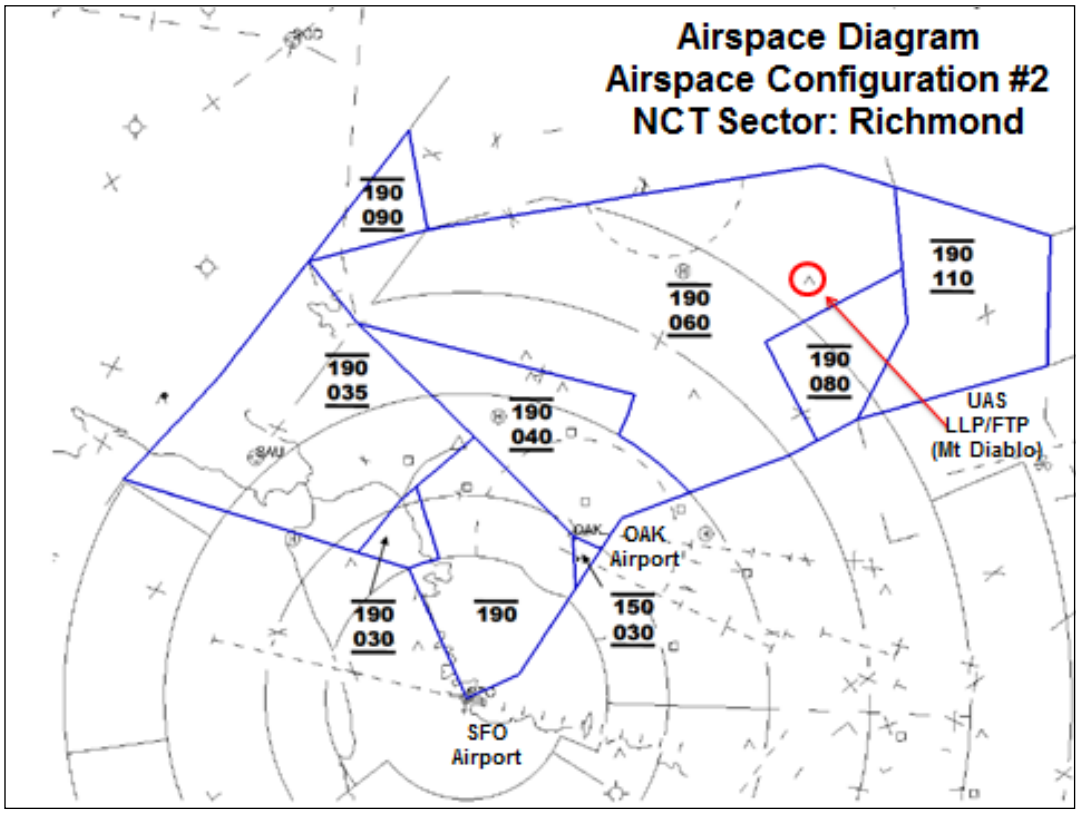

Figure 4-10 Configuration 2, Richmond Sector Diagram

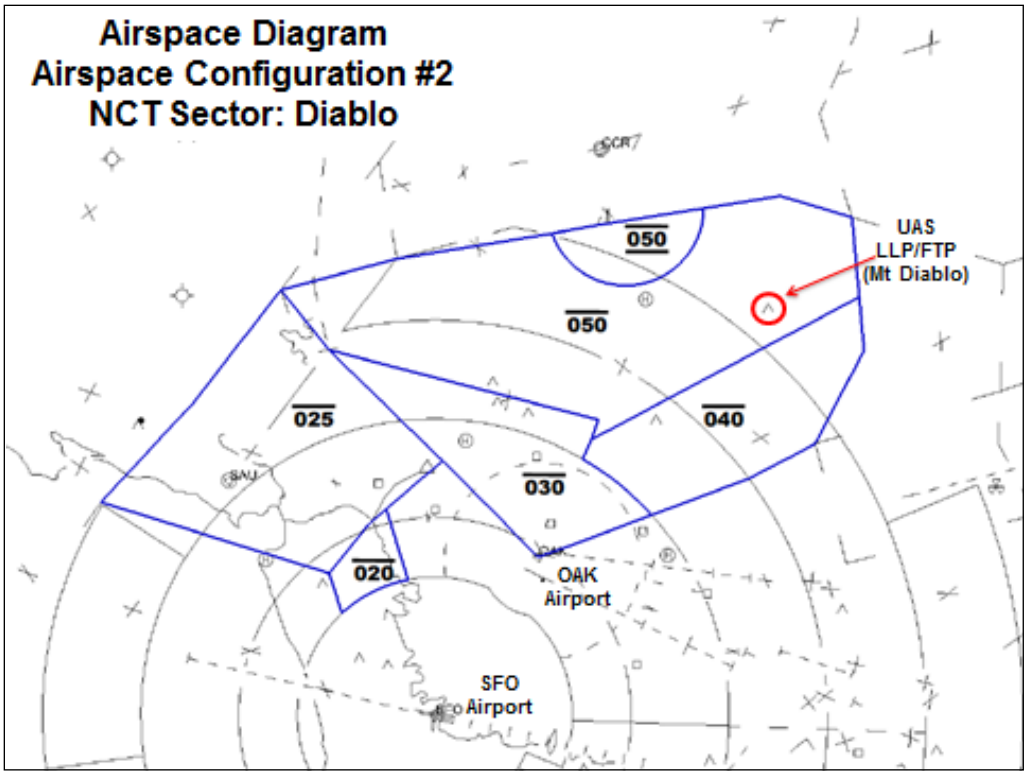

Figure 4-11 Configuration 2, Diablo Sector Diagram

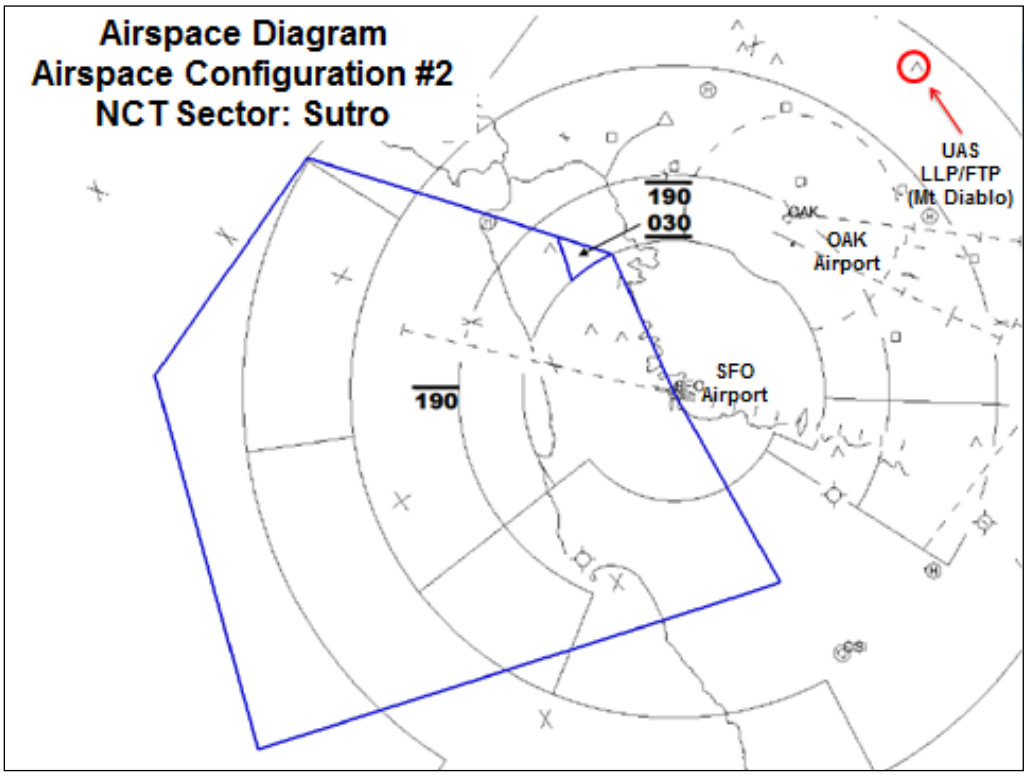

Figure 4-12 Configuration 2, Sutro Sector Diagram

Figure 4-13 depicts the airspace with manned aircraft tracks in the baseline scenario. No UAS operations were injected into the baseline scenario and all aircraft were manned, following standard arrival and departure routes.

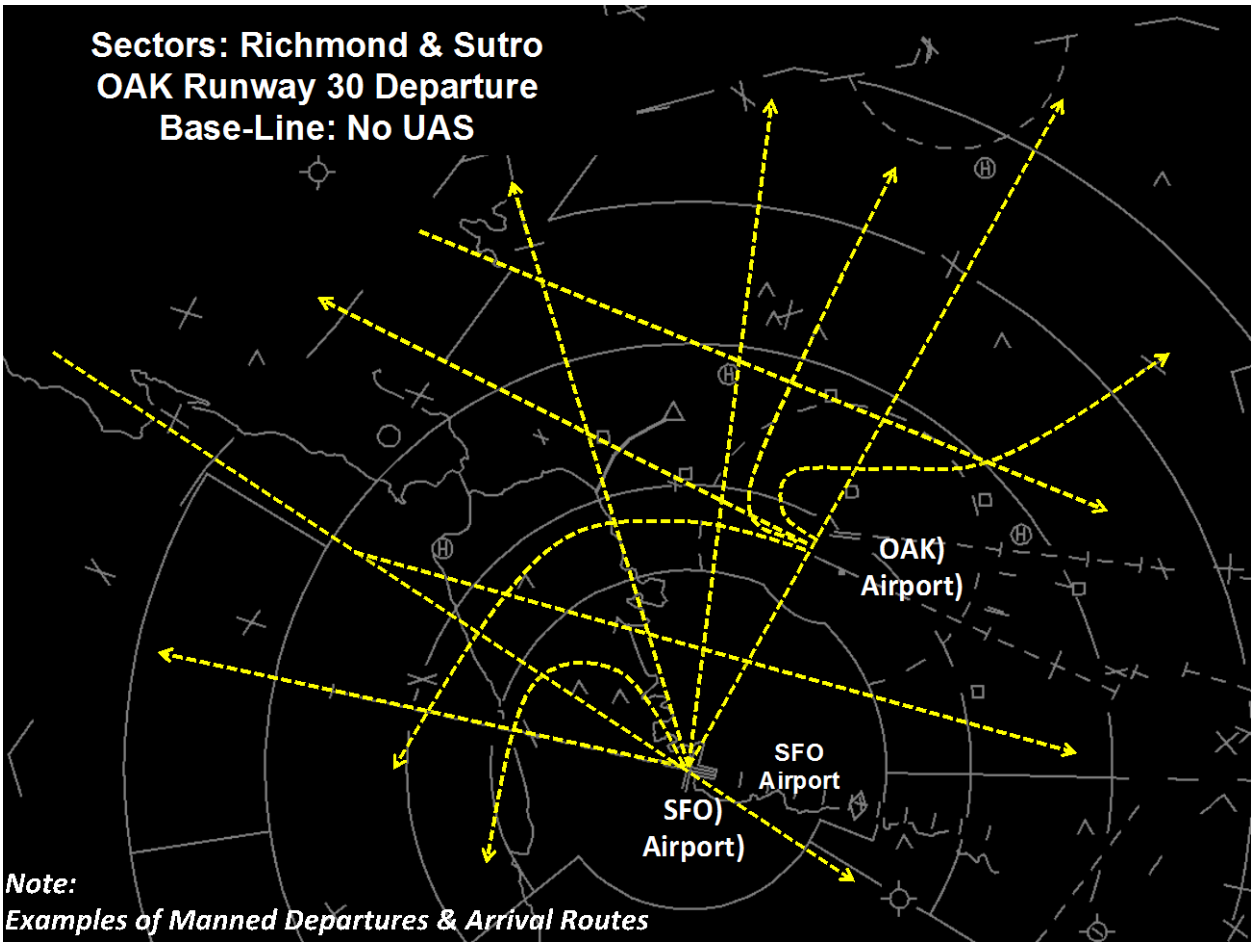

Figure 4-13 Configuration 2, Baseline

For the lost link-cruise scenario shown in Figure 4-14, the UAS departed OAK Runway 30 with a filed route of flight to the southwest. The UAS experienced a lost link after departure before control transfer to the next facility. The UAS pilot advised ATC of the lost link via the emergency land line, and complied with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'). The UAS entered the COA-defined holding/loiter pattern at the LLP and remained in the established pattern throughout the remainder of the scenario. Although the initial lost-link event occurred within Sutro's airspace under the control of the Sutro controller, the location of the LLP required that the UAS reverse course and transition into Richmond's airspace. The UAS course reversal to the LLP, although expected as the pre-programmed lost-link procedure, placed the UAS on a course that conflicted with most of Richmond's departure flows from SFO and OAK.

The intent of this scenario was to examine a lost link during a transitional phase of flight between departure and initial cruise, and the coordination required between two adjoining sectors when the defined UAS LLP is located outside of the original event sector.

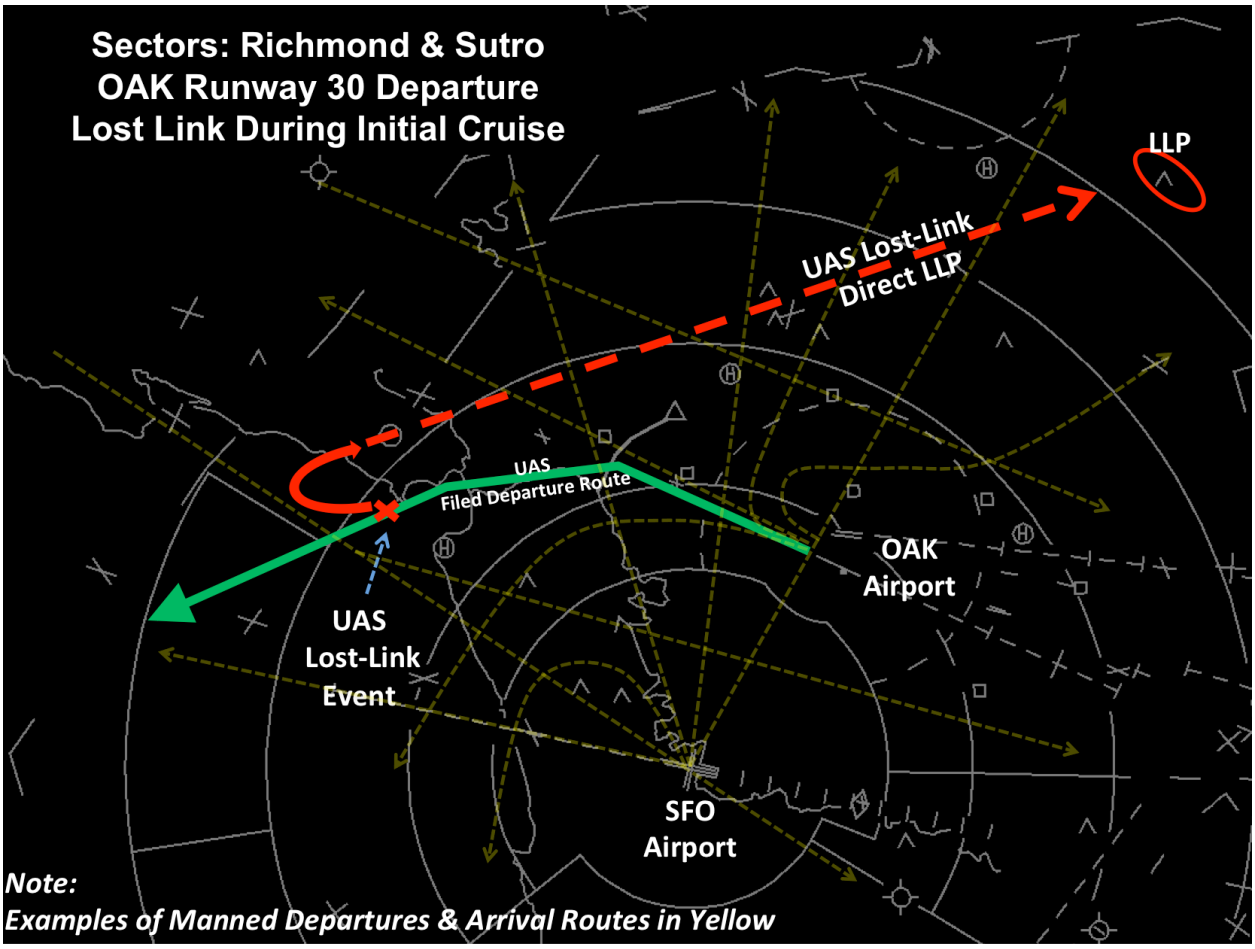

Figure 4-14 Configuration 2, Lost Link-Cruise

For the flight termination scenario depicted in Figure 4-15, the UAS departed OAK Runway 30 with a filed route of flight to the east, under jurisdiction of the Richmond controller. The UAS experienced a lost link after departure, before control transfer to the adjacent NCT sector. The UAS pilot advised ATC of the lost link via the emergency land line and complied with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'). After established in the holding pattern at the LLP, an unknown mechanical failure of the UAS resulted in a slow descent and eventual flight termination below the LLP. Due to the nature of the lost link, the UAS pilot was unaware of any mechanical issues with the aircraft or that the vehicle had departed the established lost-link holding pattern, and was therefore unable to verify any data about the aircraft when asked by ATC. The lost-link and flight termination events all occurred within the Richmond controller's airspace.

This scenario was intended to examine ATC's response to an eventual flight termination of an unmanned aircraft. The UAS descent from holding was designed to be initiated at a slow and

predictable rate to give ATC as much time as possible to recognize and plan for the possible loss of the aircraft.

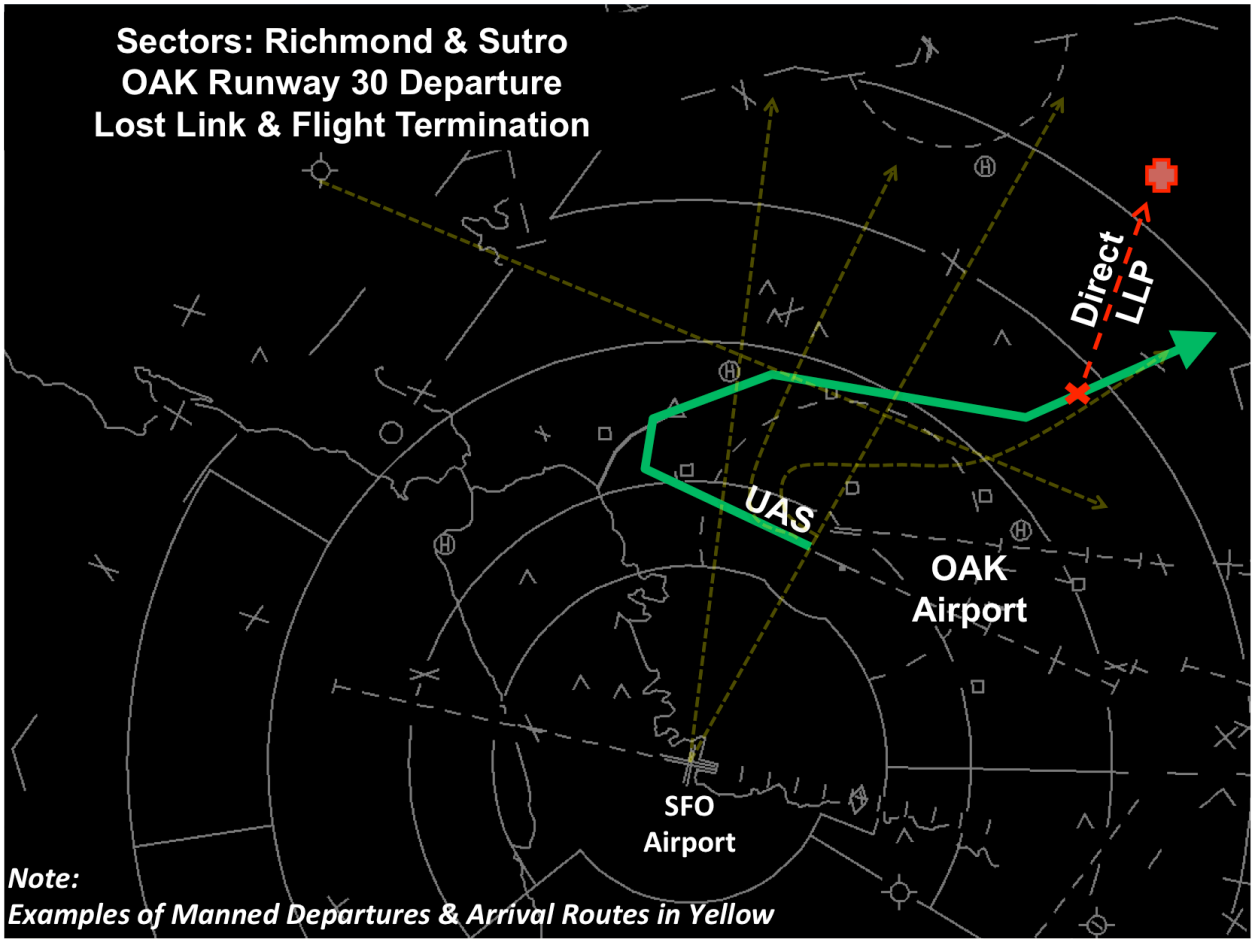

Figure 4-15 Configuration 2, Flight Termination

For the Lost Comm scenario shown in Figure 4-16, the UAS departed OAK Runway 30 with a filed route of flight to the south. Immediately after departure and initial contact with ATC, the UAS experienced a loss of radio transmitting capability. The UAS pilot retained radio receiver capability and after a scripted delay of approximately one minute the UAS pilot advised ATC of the failure via the emergency land line and awaited instructions from ATC. The UAS pilot was scripted to request a clearance to return to OAK from ATC, which required additional coordination between the FLM, UAS pilot, ghost controllers, and ATCS. There was no lost link associated with this failure and the UAS was responsive to UAS pilot command & control and ATC instructions.

Although the initial communications failure occurred while the UAS was under the control jurisdiction of Sutro, the revised clearance to OAK placed the UAS within the delegated airspace of Richmond, and was handled similarly to a normal Oakland arrival.

This scenario was intended to examine how ATC would handle a partial radio communications failure, and if there would be any differences in handling from a manned aircraft experiencing a similar failure. This situation also presented an opportunity to examine ATC's use of the UAS emergency land line.

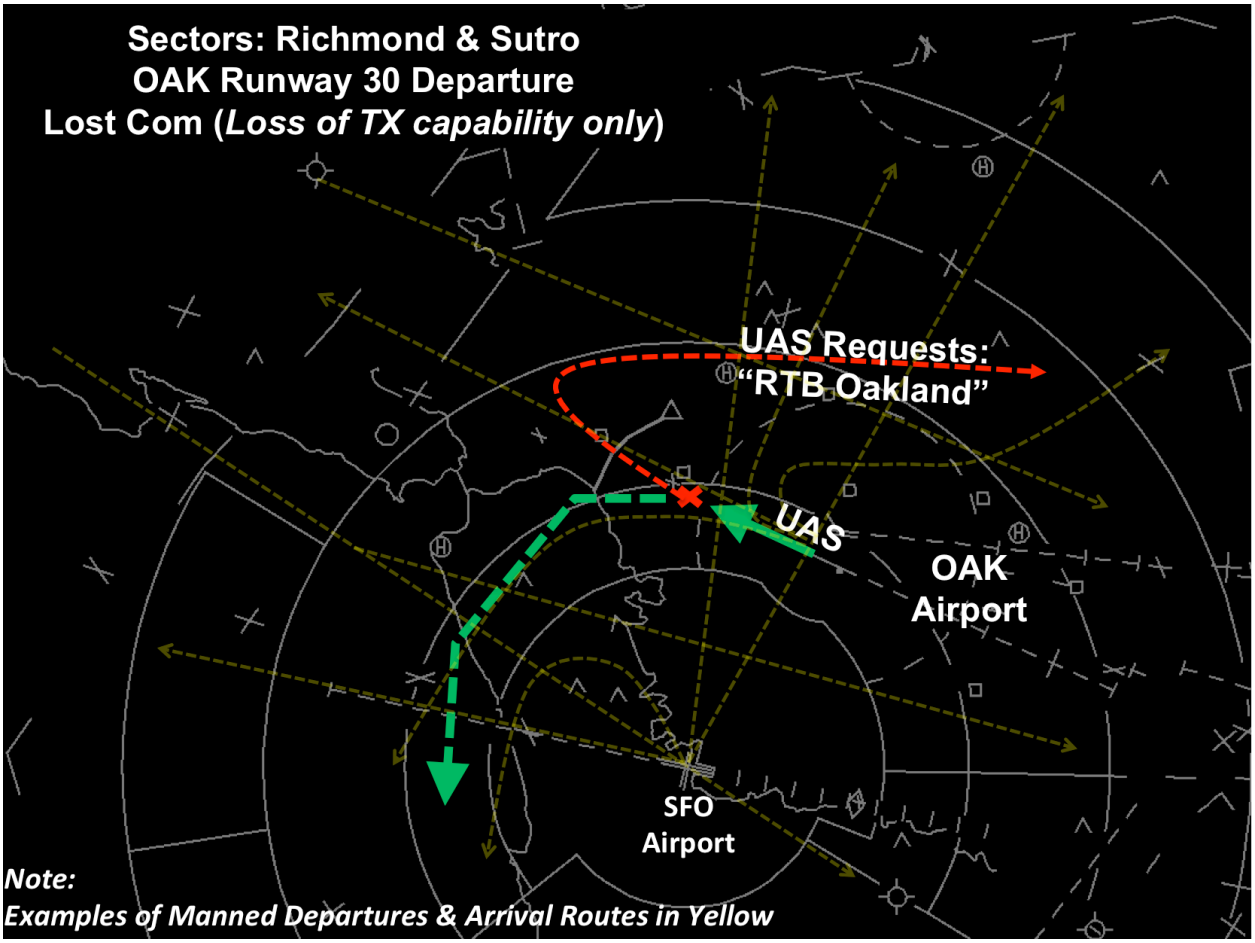

Figure 4-16 Configuration 2, Lost Comm

For the fly-away scenario shown in Figure 4-17 , the UAS departed OAK Runway 30 with a filed route of flight to the northeast. After departure, the UAS experienced a lost link and advised ATC of the failure via the emergency land line. The event occurred as the UAS transitioned to the En Route phase of flight, prior to control transfer to the next ATC facility. The UAS experienced a fly-away condition and did not comply with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'). The UAS turned the opposite direction, and proceeded Direct FARRA intersection, which is approximately 30 NM west of Oakland, and initiated a climb to 10,000'. Due to the nature of the lost link, the UAS pilot was unable to advise ATC of any maneuver other than the programmed lost-link procedure. Although the initial lost-link event occurred within Richmond's airspace, under the control of the Richmond controller, the unexpected UAS course reversal during the fly-away placed the UAS on a course that conflicted with Richmond's and Sutro's departure flows from SFO and OAK. The UAS route during the fly-away also conflicted with SFO arrival traffic, under the control jurisdiction

of another overlying NCT sector, which required inter-facility coordination to resolve any potential losses of separation. The UAS fly-away route placed the UAS in close proximity to the NCT/ZOA airspace boundaries, requiring additional inter-facility coordination.

This scenario was designed to examine ATC's ability to adapt to a UAS that operates contrary to the expected lost-link procedure during the transition from departure to the En Route phase of flight.

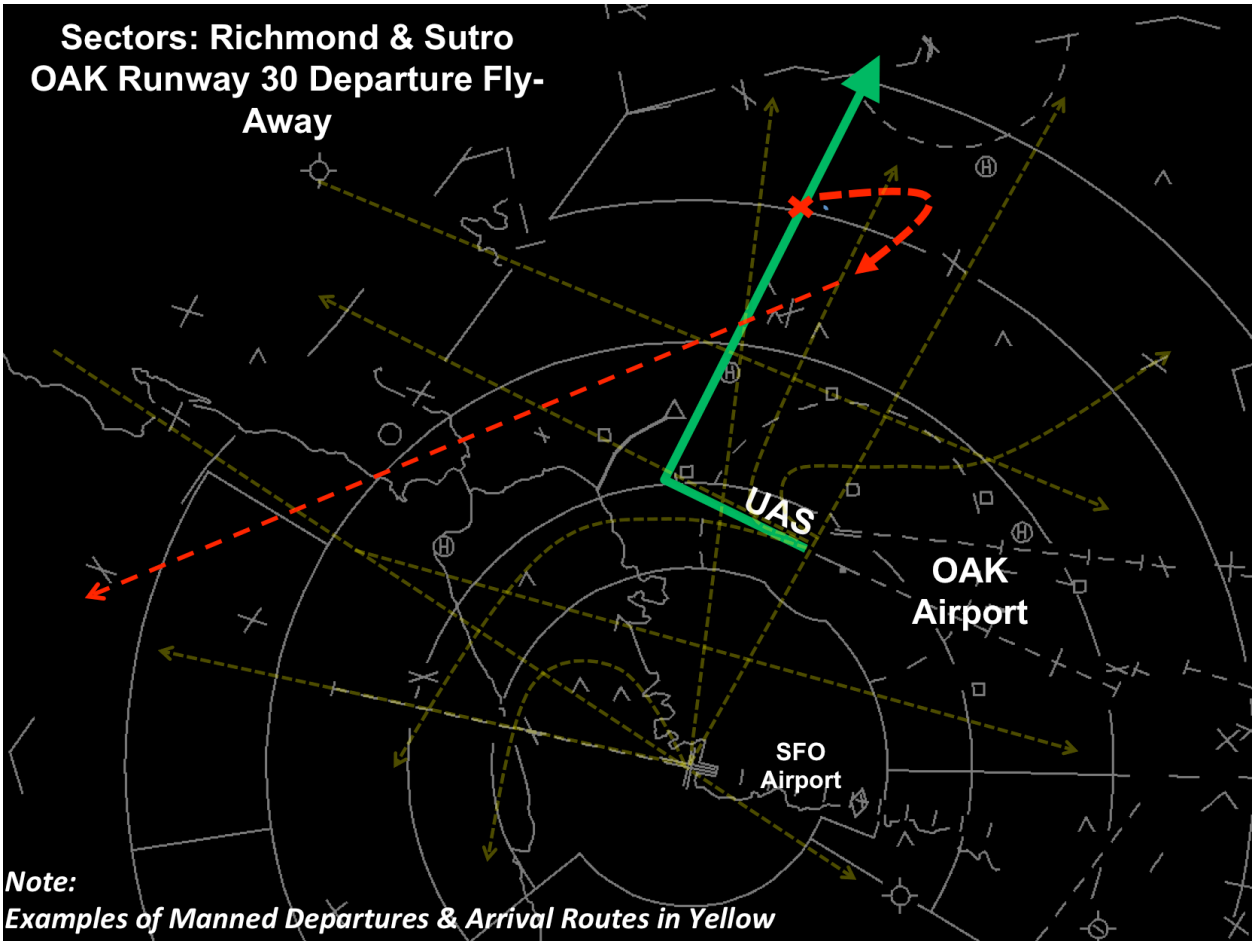

Figure 4-17 Configuration 2, Fly-away

For the engine failure scenario depicted in Figure 4-18, the UAS departed OAK Runway 30 with a filed route of flight to the south. After departure, and during the initial cruise portion of the flight, the UAS pilot advised ATC of a mechanical issue with the engine. The initial advisory was followed by a request to return to Oakland for a full-stop landing. After several minutes, the UAS pilot advised ATC the failure had progressed and that the aircraft was no longer able to maintain the assigned altitude(s). The UAS pilot requested an immediate clearance, Direct LLP/Mt. Diablo. Before the UAS reached the LLP, the UAS pilot advised ATC of a total engine failure and that the aircraft would be forced to terminate its flight. The UAS continued a slow descent below radar coverage, and the UAS pilot eventually advised ATC of flight termination and loss of the aircraft. Due to the dynamic and progressive nature of the failure and the number

of possible options for ATC, the scenario allowed for several responses from the UAS pilot, depending upon geographic location at the time of total engine failure. If over water, the UAS pilot would have solicited ATCs assistance to remain over water until flight termination. If the engine failure occurred over land, the UAS pilot would request Direct LLP/Mt. Diablo.

This scenario was intended to examine any differences in ATC handling and/or priority assessment of an unmanned aircraft, as compared to a manned aircraft experiencing similar difficulties. Although the event was designed to begin while the UAS was under the control jurisdiction of Sutro, as the situation developed, the UAS would eventually transition into Richmond's airspace, which required additional coordination between the participants.

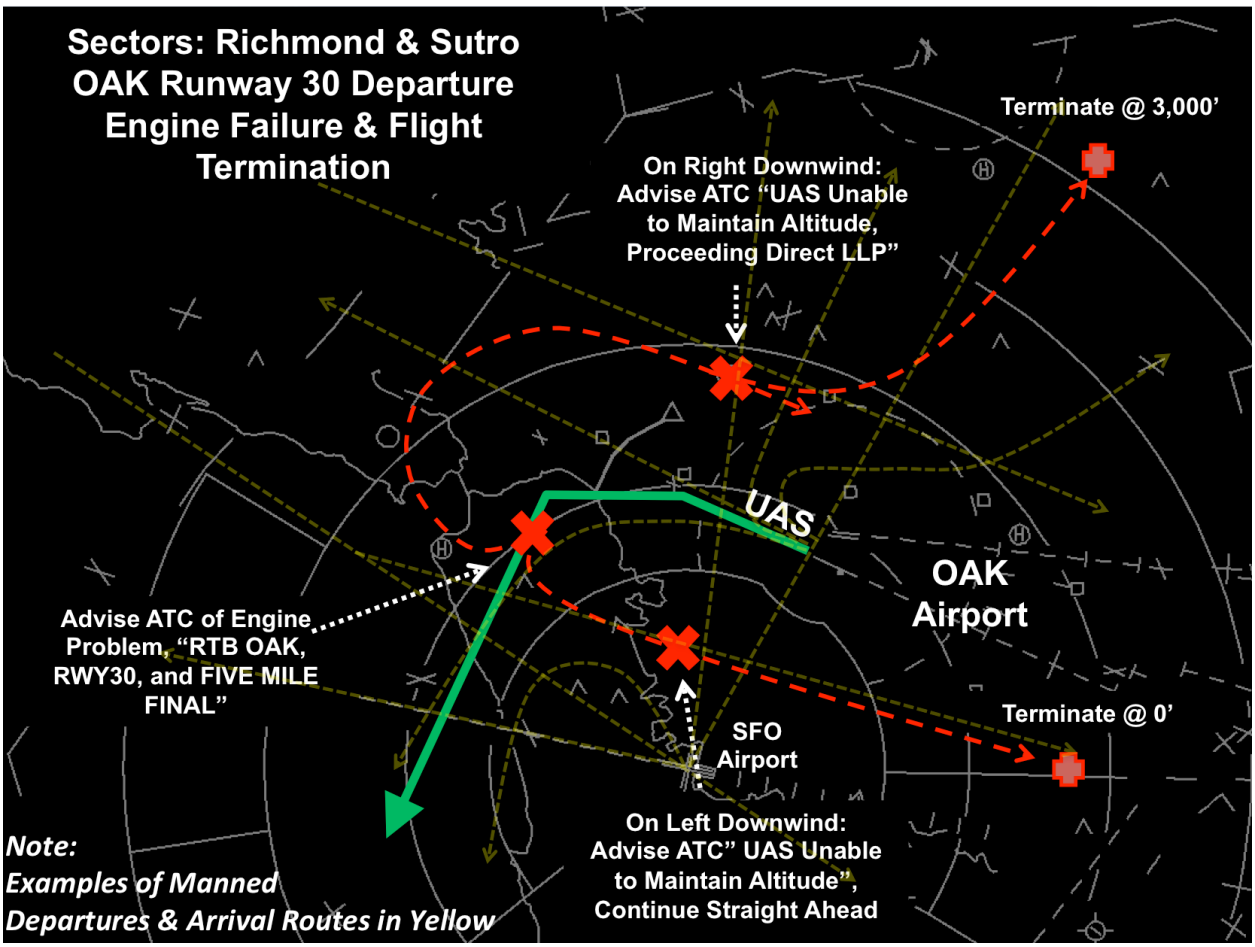

Figure 4-18 Configuration 2, Engine Failure

For the lost link-departure scenario shown in Figure 4-19, the UAS departed OAK Runway 30 with a filed route of flight to the north. The UAS experienced a lost link immediately after departure and the pilot informed ATC of the lost link via the emergency land line. The UAS complied with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000').

Approximately five minutes after reaching the LLP, the UAS pilot advised ATC that the command/control link had been re-established, and requested a return to OAK for a full-stop

landing. Although the entire lost-link event and subsequent hold at the published LLP occurred while the UAS was under the control of Richmond, additional coordination and radar handoff to an adjacent NCT sector was required when the UAS proceeded on the requested clearance to OAK.

The intent of this scenario was to examine a lost link during the initial departure phase of flight, and to examine ATC response to a link reacquisition. This is the only scenario during the study where the failure mode of the UAS was corrected in-flight.

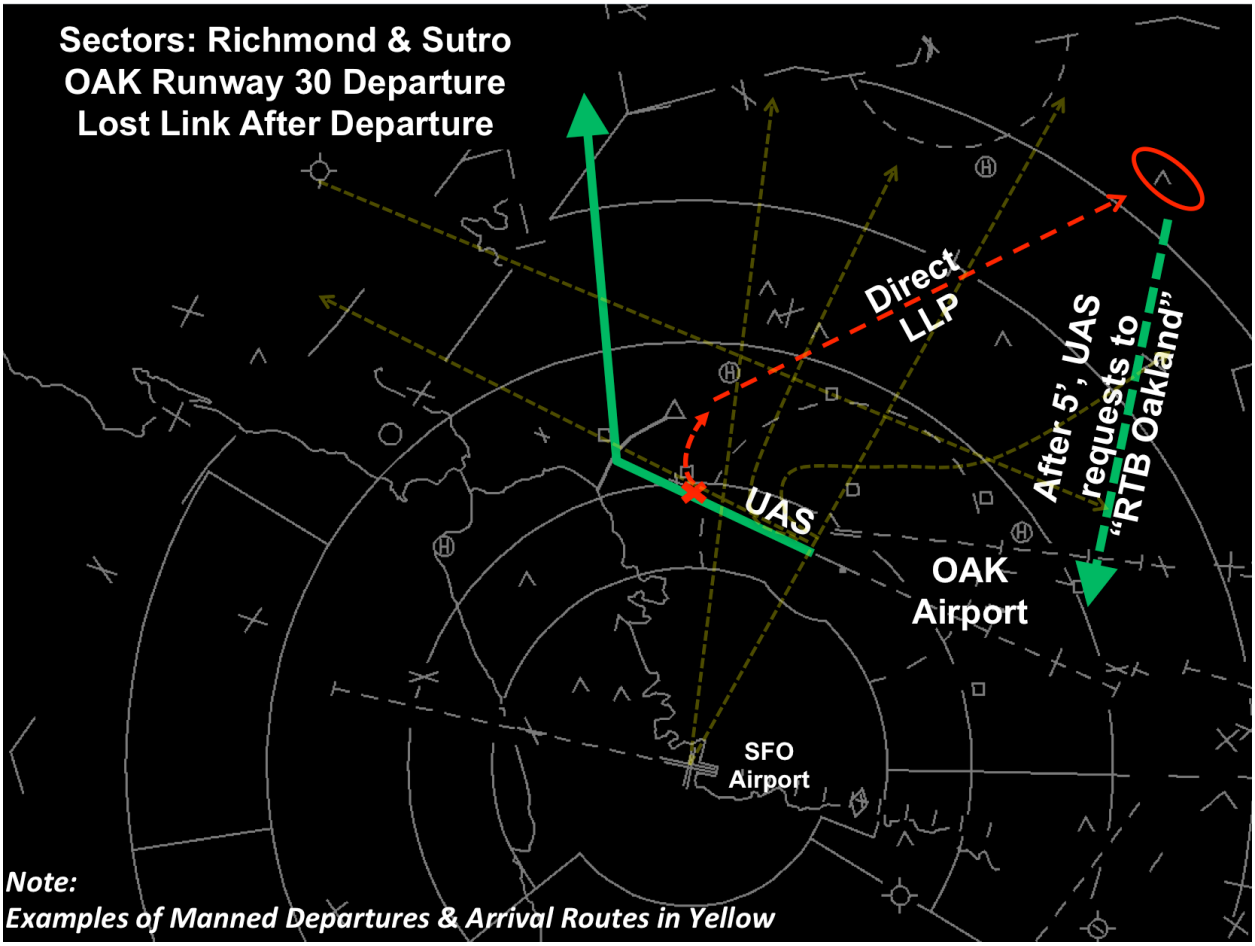

Figure 4-19 Configuration 2, Lost Link-Departure

For the multiple lost links scenario shown in Figure 4-20, two UAS departed OAK Runway 30 with staggered departure times. Each UAS had different filed routes of flight, for different destinations. Since the scenario involved two UAS, NCT controllers were pre-briefed that the two UAS filed for different lost-link altitudes: 5,000' and 6,000' for UAS #1 and UAS #2, respectively. UAS #1 departed first and proceeded uneventfully to the north. After ATC had completed transfer of control of UAS #1 to the adjacent facility, ZOA, the second UAS departed OAK Runway 30 and proceeded via the requested flight plan to the northeast. UAS #2 experienced a lost link prior to control transfer to the adjacent NCT sector, and the pilot advised

ATC via the emergency land line. UAS #2 complied with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 6,000').

Simultaneously, UAS #1 experienced a lost link while under the control jurisdiction of ZOA. ZOA controllers advised NCT of the UAS lost link, and the aircraft's intended routes of flight (Direct LLP/Mt. Diablo and maintain 5,000'). ZOA controllers initiated an automated radar handoff of the UAS #1 track to NCT Richmond sector.

Because the lost links occurred well after departure, both UAS initiated descents from altitudes much higher than the pre-programmed lost-link altitudes. The two UAS converged at the LLP as each descended to its respective lost-link altitude. These simultaneous lost-link procedures did not guarantee separation, even though the lost-link pre-programmed altitudes were different.

The intent of this scenario was to examine multiple UAS flights within the same facility and sector, with conflicting lost-link procedures.

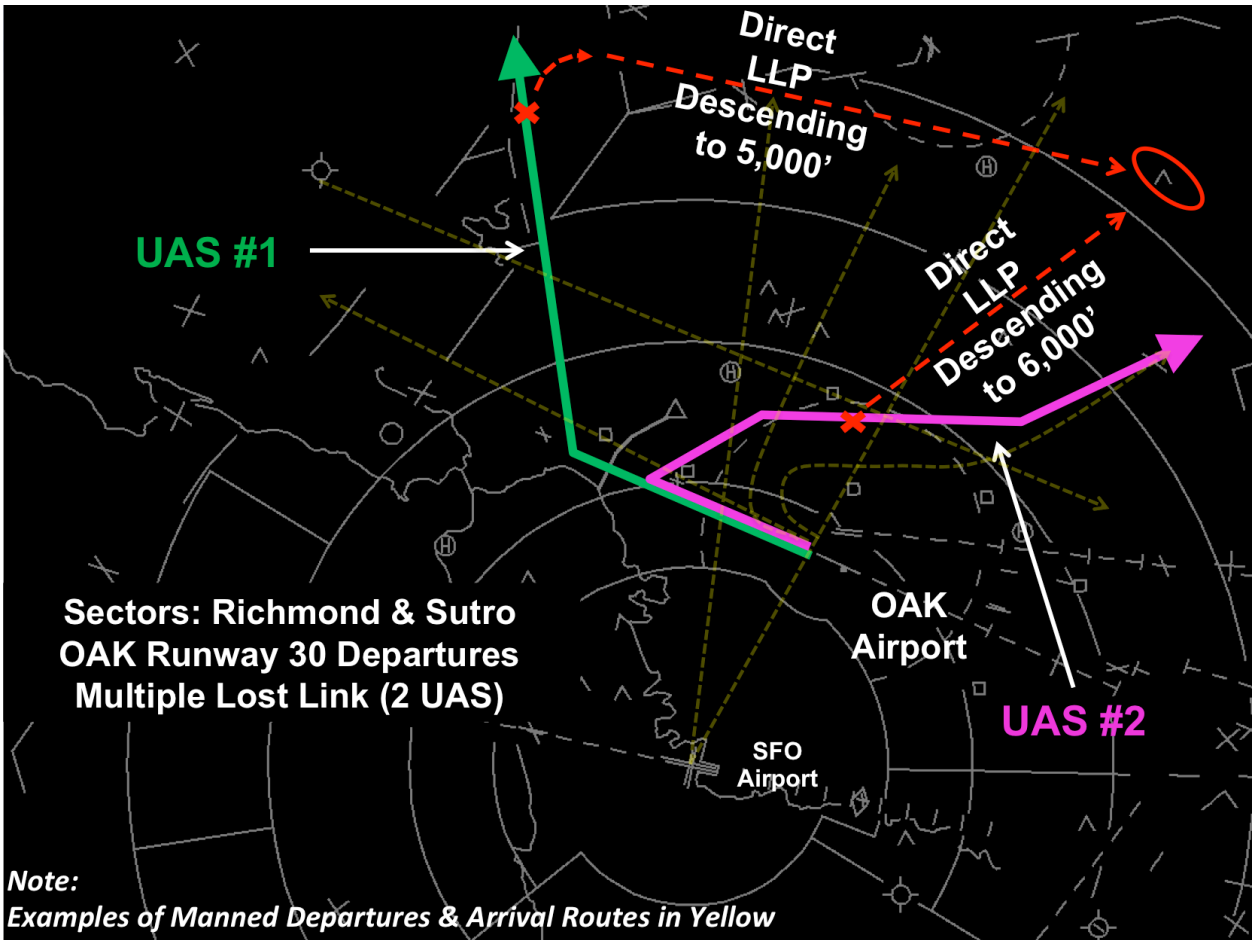

Figure 4-20 Configuration 2, Multiple Lost Links

4.7.3 Airspace Configuration 3 and Detailed Traffic Scenarios

OAK and SFO departures were configured for West Plan operations. During this configuration, Oakland's primary runways were 30, 28R, and 28L. The NCT Mulford and Grove sectors served as the primary arrival positions for OAK, and were the sectors of interest. Typically, arrivals to either Runway 28L or 28R were sequenced and controlled by Grove, whereas OAK arrivals to Runway 30 were sequenced and controlled by Mulford. No handoff or coordinator positions were staffed during this configuration.

Scenarios developed for Configuration 3 used the same LLP/FTP as defined in the COA, over Mt. Diablo, within the confines of an adjacent NCT sector.

Although primarily final approach sectors for OAK, Mulford and Grove provide ATC approach and departure services to two additional satellite airports, LVK and HWD. LVK is located approximately 20 NM northeast of OAK, and the Grove sector provides IFR departure control services to aircraft departing Runway 25L and 25R at LVK. Approach control services to LVK would normally be provided by another adjacent NCT. HWD is located approximately 6 NM east of OAK, and the Mulford sector provided both approach and departure control services.

During Configuration 3, IFR operations at HWD were uniquely complex, due to the proximity of the airport to the Oakland final approach course. All HWD IFR arrivals and departures must be sequenced with respect to OAK arrival traffic to Runway 30, which also includes all UAS arrivals. Proximity of the SFO final approach course resulted in additional airspace constraints that contributed to the airspace complexity when HWD IFR departures were involved.

Per the COA developed for this study, the UAS LLP was established over a geographical landmark, Mt. Diablo, approximately 17 NM northeast of OAK. Together with the COA-mandated lost-link holding altitude of 5,000', the LLP was outside the vertical and lateral confines of Mulford/Grove airspace. The airspace diagrams of the Mulford and Grove sectors for Configuration 3 are depicted in Figure 4-21 and Figure 4-22, respectively.

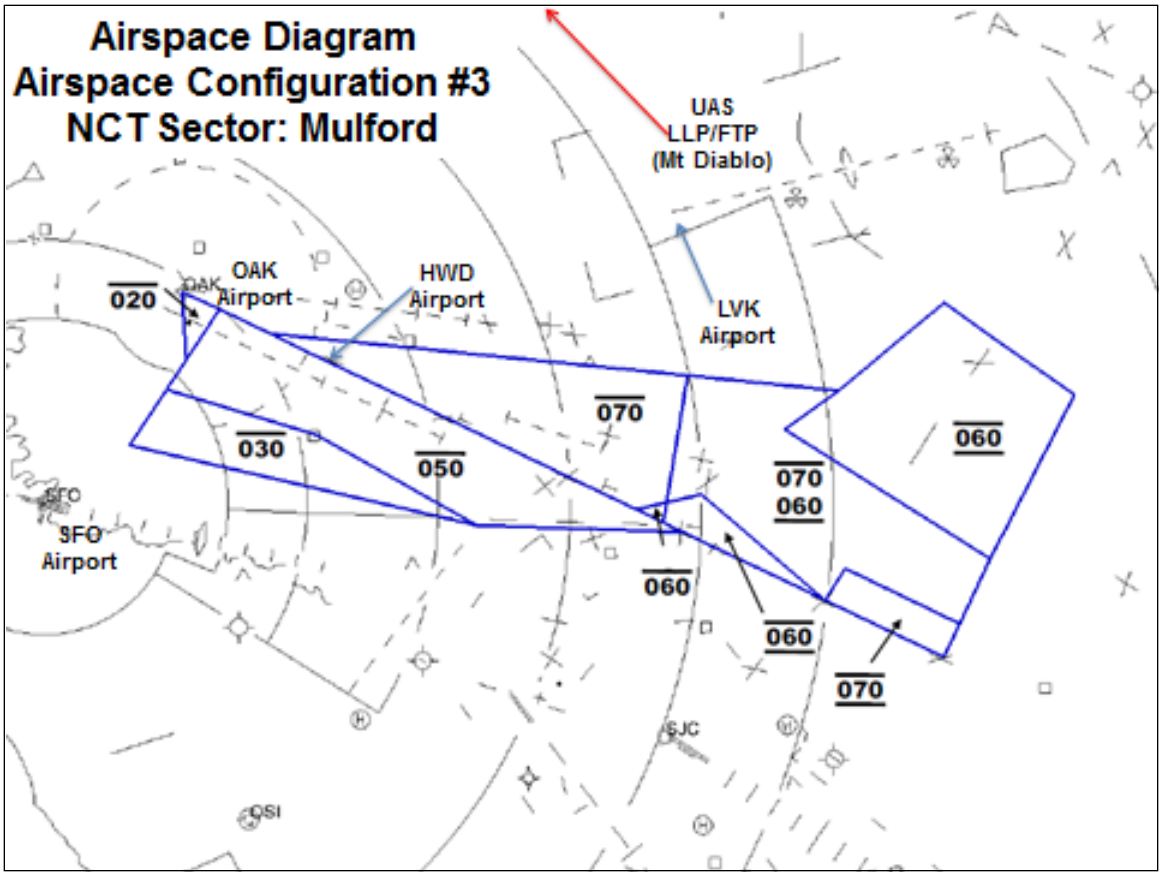

Figure 4-21 Configuration 3, Mulford Sector Diagram

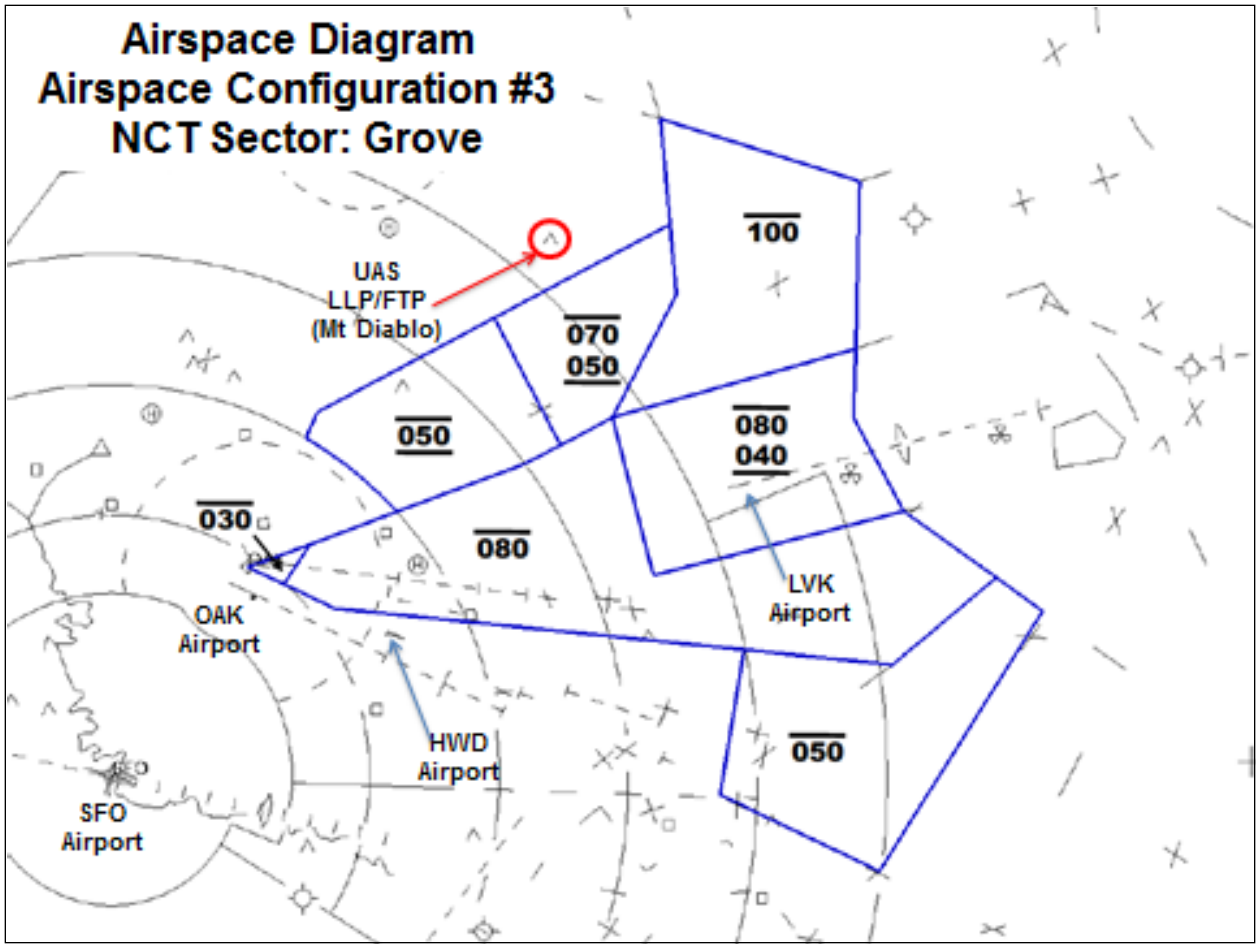

Figure 4-22 Configuration 3, Grove Sector Diagram

Figure 4-23 depicts the airspace with manned aircraft tracks in the baseline scenario. No UAS operations were injected into the baseline scenario and all aircraft were manned, following standard arrival and departure routes.

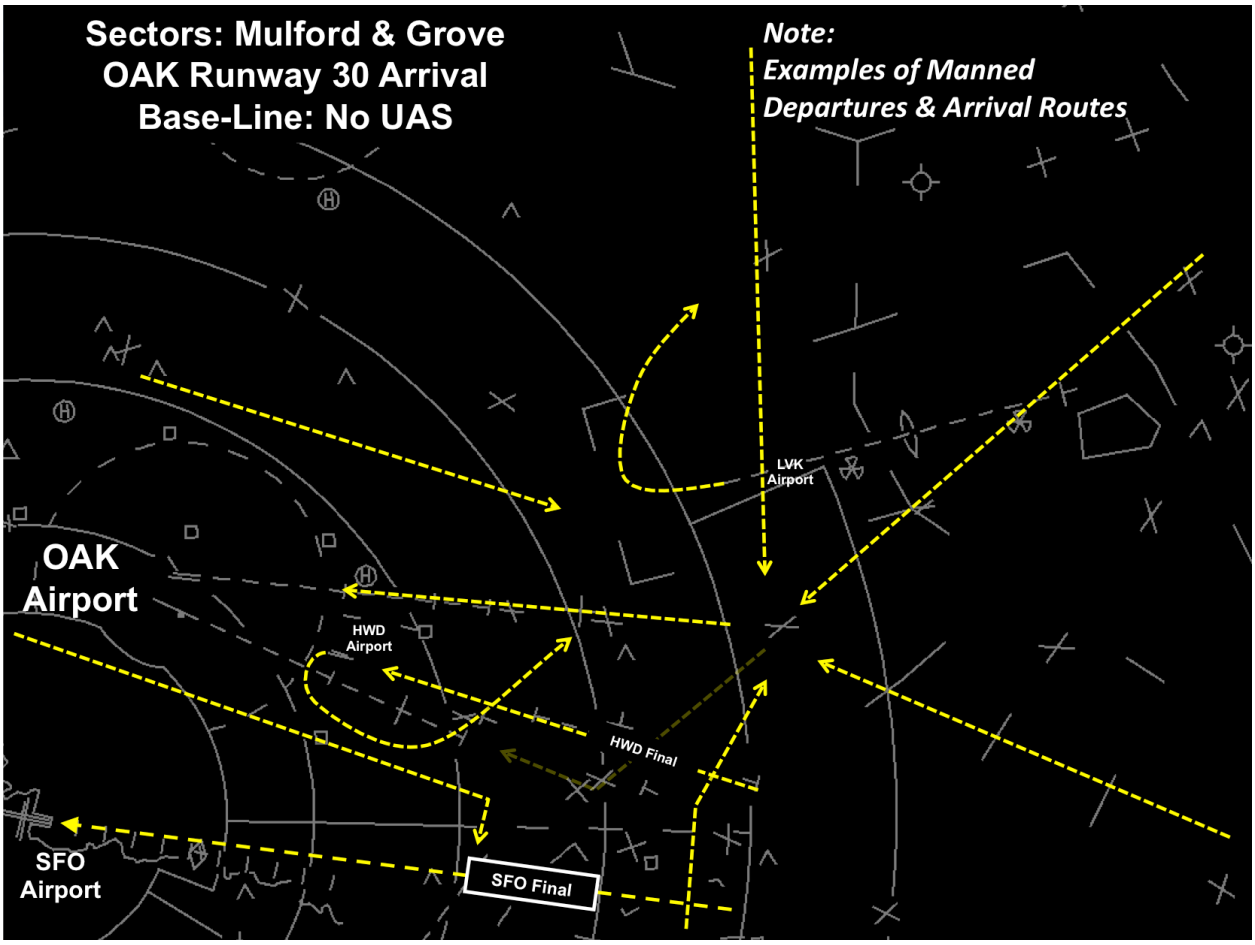

Figure 4-23 Configuration 3, Baseline

For the lost comm scenario depicted in Figure 4-24, the UAS was an arrival from the northwest to OAK Runway 30 and handed off to either Mulford or Grove. The handoff recipient for this particular arrival route was dependent upon individual controller workload and preference and since the UAS was a Runway 30 arrival, control of the UAS was eventually transferred to the Mulford sector for final approach sequencing. After initial radio check-in with ATC (either Mulford or Grove), the UAS experienced a loss of radio communications. After approximately one minute, the UAS pilot advised ATC of the communications loss via the emergency land line, and awaited instructions from ATC. There was no lost link associated with this failure and the aircraft was still responsive to UAS flight pilot command & control.

This scenario was designed to examine how ATC would respond to a UAS experiencing a loss of radio communications, and if the actions would differ from established procedures for manned aircraft. The scenario was also designed to examine the effect on ATC of having an emergency communications land line available during UAS operations with compromised radio communications.

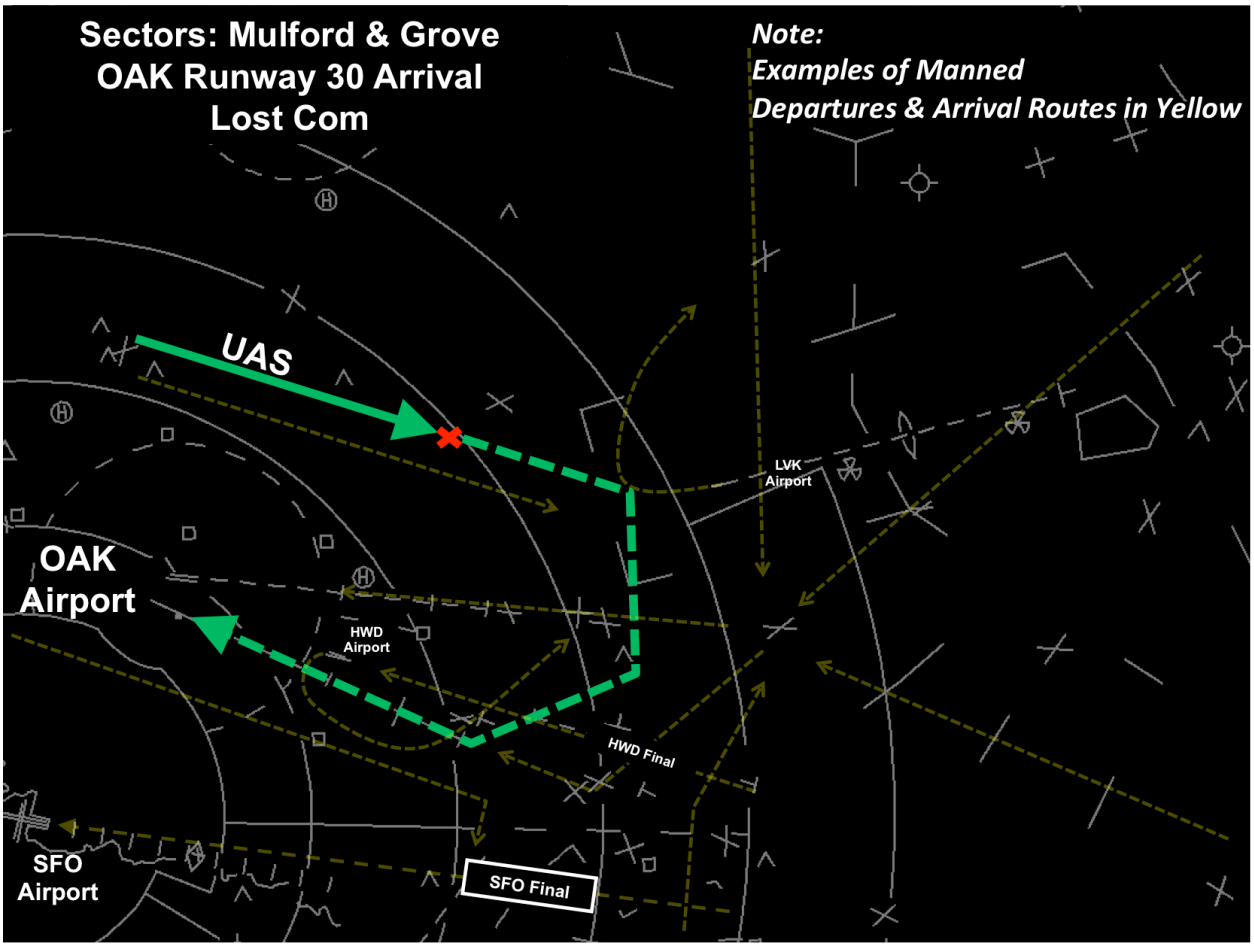

Figure 4-24 Configuration 3, Lost Comm

In the fly-away scenario shown in Figure 4-25, the UAS was an arrival from the northeast to OAK Runway 30, handed off to the Mulford sector. Prior to intercepting the final approach course, the UAS experienced a lost link and the UAS pilot advised ATC via the emergency land line. Instead of complying with the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'), the UAS continued on the last assigned heading, which placed the aircraft in conflict with SFO arrival traffic in adjacent sectors. Due to the nature of the lost link, the UAS pilot was unable to advise ATC of any maneuver other than the expected lost-link procedure.

This scenario was designed to examine ATC's ability to adapt to a UAS proceeding contrary to the expected procedure in complex airspace. The scenario also examined the inter-facility coordination between controllers, and the effects of a UAS fly-away on adjacent sectors.

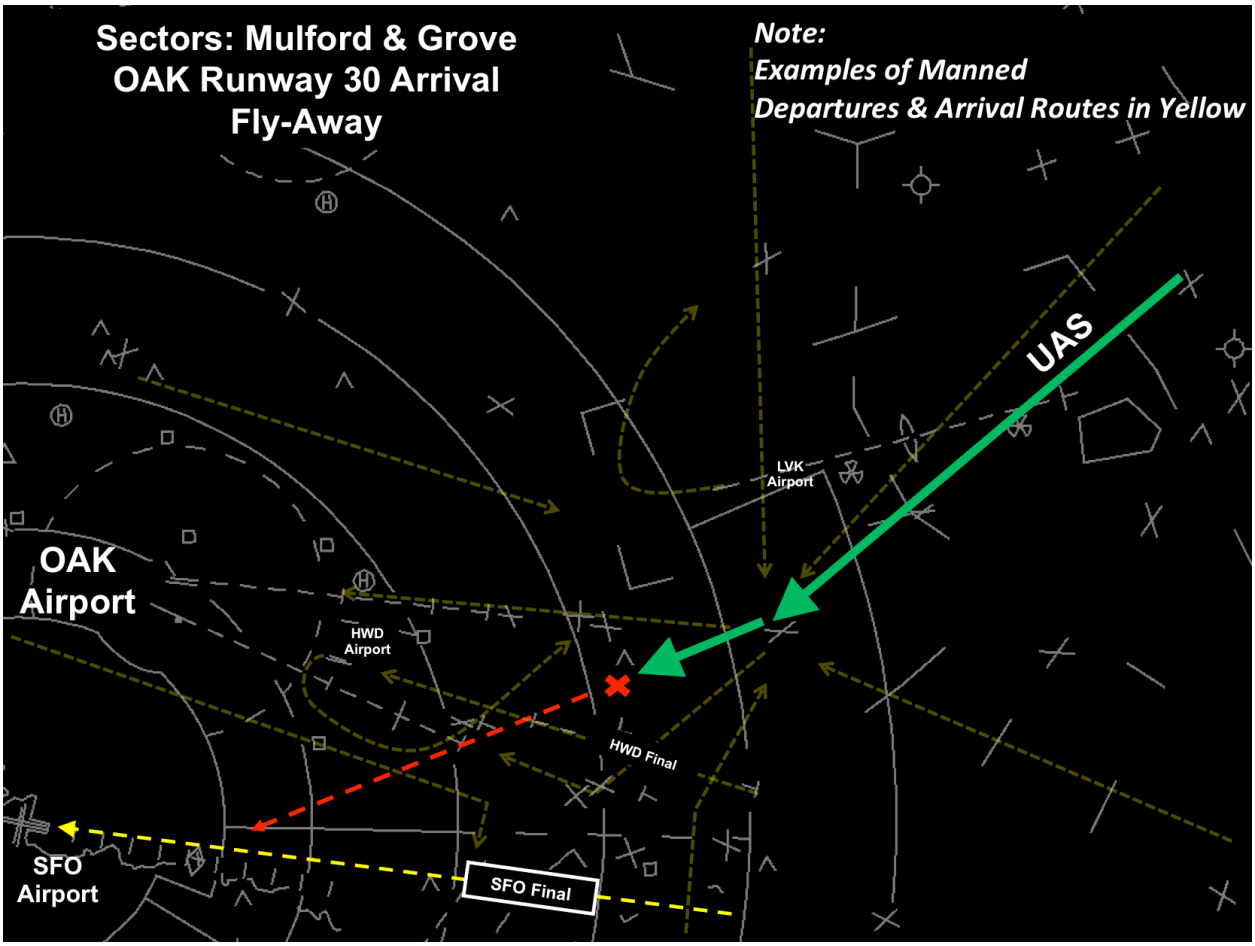

Figure 4-25 Configuration 3, Fly-away

In the emergency divert scenario depicted in Figure 4-26, the UAS was an arrival from the northwest to OAK Runway 30, and was handed off to either Mulford or Grove. The handoff recipient for this particular arrival route was dependent upon individual controller workload and preference, and since the UAS was a Runway 30 arrival, control of the UAS was eventually transferred to the Mulford sector for final approach sequencing. The UAS did not experience any abnormalities and was sequenced with the other manned arrival traffic to OAK Runway 30. Approximately 20 minutes into the scenario, OAK ATCT advised the NCT Mulford controller that Runway 30 was closed indefinitely due to a disabled aircraft. The timing of the runway closure was intended to occur before the UAS was established on the final approach course, which allowed ATC time to prioritize and handle manned aircraft closer to the airport. ATC was expected to solicit intentions from the manned aircraft and possibly offer an alternative runway at OAK, (either 28L or 28R). It was expected that ATC would advise the UAS pilot of the runway closure and solicit intentions. Per the COA, the UAS was unable to accept any runway at OAK other than Runway 30, and when asked by ATC, the UAS pilot requested a destination change to Edwards Air Force Base.

The intent of the scenario was to observe ATC's response to a UAS that has no alternative runway option at Oakland.

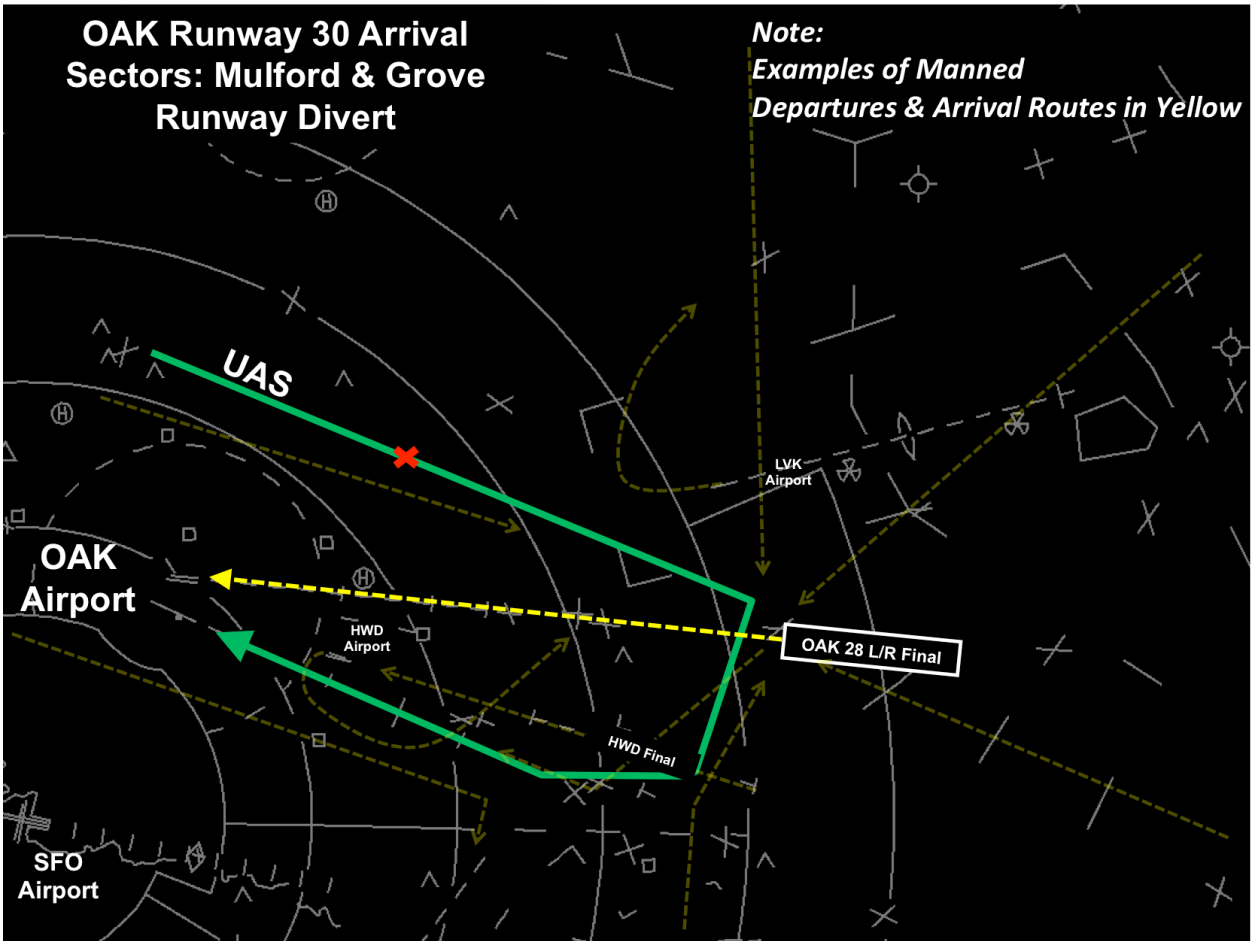

Figure 4-26 Configuration 3, Emergency Divert

In lost link scenario shown in Figure 4-27, the UAS was an arrival from the southeast to OAK Runway 30, and was handed off to the Mulford sector. The UAS experienced a lost link on final approach prior to frequency change to OAK ATCT. The flight crew informed ATC of the lost link via the emergency land line, and advised ATC of the expected lost-link procedure (Direct LLP/Mt. Diablo and maintain 5,000'). Although the lost-link event occurred while the UAS was under the control of Mulford, the lost-link procedure required a transition through the delegated airspace of Grove and into another NCT adjacent sector, which conflicted with normal traffic flows in all affected sectors. This required additional coordination between ATC and the ghost controllers.

The intent of this scenario was to examine a lost link during the arrival phase of flight, and to examine the effects and inter-facility coordination for a UAS lost link, even when the aircraft follows the expected procedure.

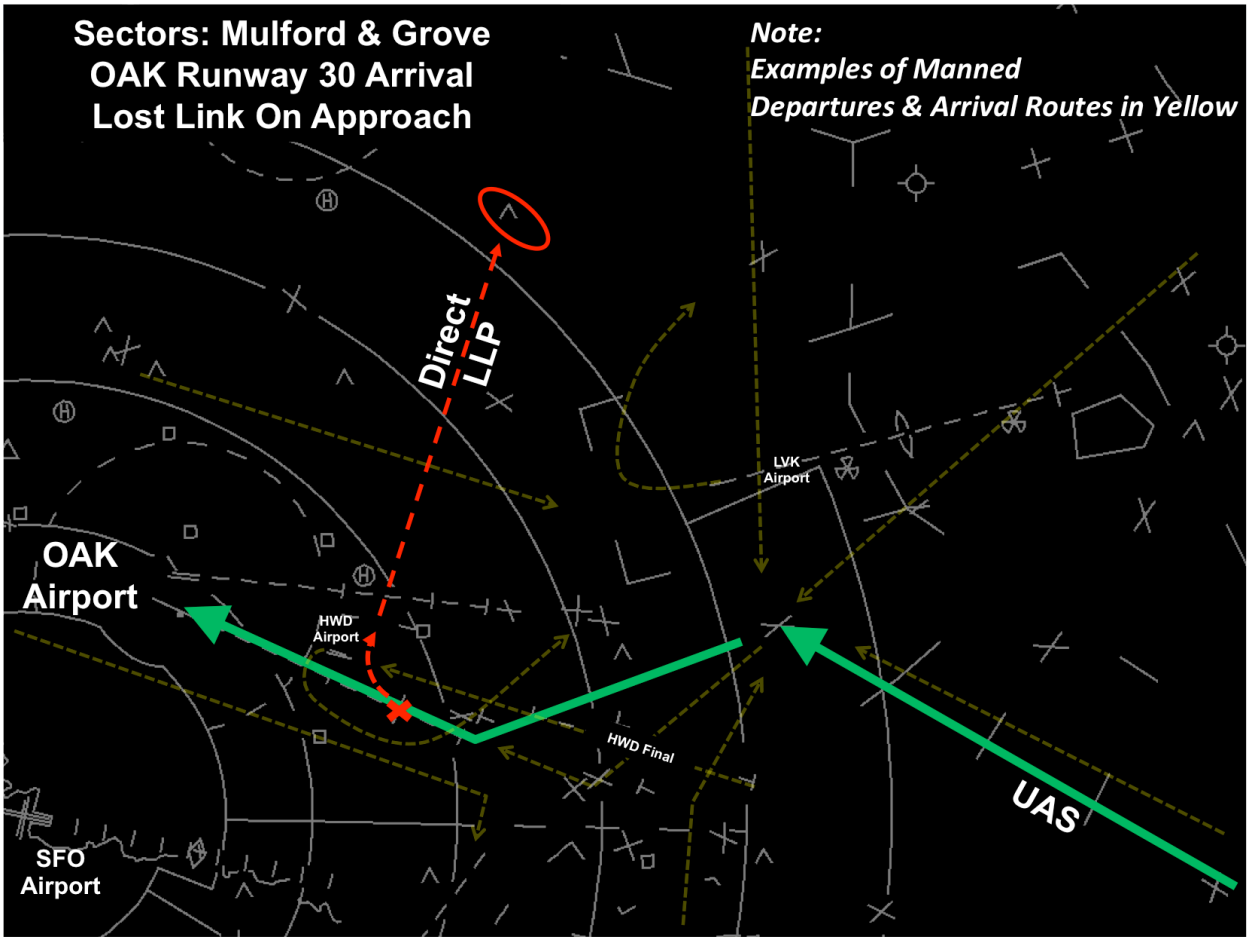

Figure 4-27 Configuration 3, Lost Link

4.8 Pre-testing

In support of scenario development, researchers conducted a cognitive walkthrough with the support of current ATC and UAS pilot SMEs. During this activity, researchers walked through specific scenarios representative of the operational concept, evaluating the task at each step to collect feedback. This helped researchers develop more realistic scenarios and provided users with the ability to identify areas of concern. After the completion of scenario and software development, a formal simulation validation session was conducted. The equipment required for the HITL was tested during this validation session, which began several weeks before the simulation. Each of the test conditions, scenarios, and collected system measures used during the simulation were also tested. The research team and other simulation support personnel used the validation session period to practice all simulation procedures. This helped the team ensure that the system hardware and software were working correctly and helped the team identify any issues to be addressed prior to the start of the simulation. The team used the validation session to ensure all data collection devices were functioning as required.

4.9 Design

4.9.1 Independent Variables

The main factor of importance in the study was the scenario condition, which consisted of either the baseline scenario without UAS or one of the scenarios where one or two UAS were present. The second factor in the study was the controller position/sector the participants controlled during the traffic scenarios. For the departure scenarios, the controllers operated the Richmond, Sutro, and CI-1 positions. For the arrival scenarios, the controllers operated either the Mulford and Grove positions, or the Grove and Grove handoff positions.

4.9.2 Simulation Measures

The simulation measures were generally categorized into system effectiveness measures, human factors measures, and observer ratings.

System Effectiveness Measures:

The NIEC has an extensive data collection system that records aircraft track and status information during the simulation. The aircraft track and status data was analyzed to produce objective system effectiveness measures in the critical areas of safety, capacity, efficiency, and communications (Buckley, et al, 1983; Stein & Buckley, 1992).

Human Factors Measures:

The post-scenario questionnaire was the main source of subjective data that measures controller performance, workload, and SA in each of the experimental conditions. The WAKs were used to provide an additional measure of workload using a real-time technique as controllers performed the traffic scenarios.

Observer Ratings:

SMEs used the observer rating form to provide subjective ratings of controller performance in each of the experimental conditions. The SMEs were experienced observers who were accustomed to training controllers and evaluating ATC performance. SMEs often detect controller actions that affect safety, capacity, and efficiency that cannot be measured by objective techniques.

For a list of the measures collected see Table 4-3.

Table 4-3 Simulation Measures

Safety Measures
Number of Mid-Air Collisions
Number of Near Mid-Air Collisions
Number of Losses of Separation

Efficiency Measures
Number of Arrival, Departure & En Route Delays to the UAS
Number of Arrival, Departure & En Route Delays to Other Aircraft
Number of Canceled UAS Requests
Number of Canceled Requests for Other Aircraft
Number of Re-sequenced Arrivals
Number of ATCS-Initiated Holding Patterns
Number of Aircraft Affected by ATC-Initiated Holding Patterns
Number of times ATCS-Initiated Departure "Hold for Release" (HFR)
Number of Aircraft Affected by ATC Initiated Departure Holding
Capacity Measures
Number of Arrivals by Runway Complex
Number of Departures by Runway Complex
Communications
Number & Duration of Controller-to-Pilot Transmissions
Number & Duration of Pilot-to-Controller Transmissions
Number of Controller-to-Front Line Manager Transmissions
Workload
Real-Time Workload Ratings Every Four Minutes
NASA-TLX Workload Rating Scale
Questionnaire
Overall Safety & Efficiency
Overall Workload & SA
UAS Effects on Sector Management, Other Aircraft & Workload

Observer Rating Form
Maintaining Safe & Efficient Traffic Flow
Maintaining Attention & SA
Prioritizing
Providing Control Information
Technical Knowledge
Communicating
Sector Management

4.10 Procedure

4.10.1 Schedule of Events/Timeline

Over the span of ten weeks, the ten groups of controllers were scheduled for three days of participation. The first day was dedicated to the in-brief, training, and a few simulation runs; the second day to simulation runs; and the third and final test day to any remaining simulation runs and the debrief. The debrief was designed to allow participant feedback on the overall simulation. The simulation runs were counterbalanced and presented in that order to mitigate the potential for order effects. Table 4-4 depicts the daily schedule of events.

Table 4-4 Daily Schedule

Local Time	Day 1	Local Time	Day 2	Local Time	Day 3
0830	Informed Consent, In-Brief, Training	0830	Experiment Run 6	0830	Experiment Run 14
		0915	Break	0915	Break
		0920	Experiment Run 7	0920	Experiment Run 15
		1005	Break	1005	Break
		1020	Experiment Run 8	1020	Experiment Run 16
		1105	Break	1105	Break
1130	Lunch	1110	Experiment Run 9	1105	Experiment Run 17
1230	Experiment Run 1	1150	Lunch	1230	Lunch
1315	Break	1250	Experiment Run 10	1315	Buffer Run
1320	Experiment Run 2	1335	Break	1320	Break
1405	Break	1340	Experiment Run 11	1330	Post-Experiment Questionnaire & Debrief
1410	Experiment Run 3	1435	Break		
1455	Break	1450	Experiment Run 12		
1510	Experiment Run 4	1535	Break		
1555	Break	1540	Experiment Run 13		
1600	Experiment Run 5				
1700	End of Day	1630	End of Day	1700	End of Day

4.10.2 In-Briefing

On the first day of the study, introductions were made and all participants were informed of the background and objectives of the study prior to their participation. Then, the participants completed an informed consent form, which assured their anonymity and voluntary participation in the study, along with a background questionnaire to collect information relating to their ATC or UAS experience. An SME then gave an overview of the airspace, procedures, and simulated laboratory environment to familiarize participants.

4.10.3 Training and Practice Scenarios

Following the in-briefing, the participants were led to the laboratory and given an overview of the laboratory equipment. They then controlled traffic in training/practice runs. These practice runs served to familiarize participants with the test environment, allowing them to engage with simulation pilots and familiarizing them with the WAK. Practice scenarios used for the training runs were similar to, but different from the actual simulation scenarios. They were overseen by research personnel and lasted until participants were sufficiently prepared to begin data collection runs.

4.10.4 Data Collection Procedure

Data was collected in the form of audio and video recordings, TGF data collection, questionnaires, observer ratings, and other forms of operational and performance data necessary to support the study.

5 Data Analysis Methodology

Quantitative data from the questionnaires was analyzed using simple descriptive statistics, and the open-ended comments were summarized. For most of the simulation measures, inferential statistics were applied, and the results were summarized using graphs and tables.

The research team conducted separate analyses for the group of participants who controlled the departure scenarios and the group who controlled the two arrival scenarios. The simulation data for each group was analyzed using a one-way Analysis of Variance (ANOVA) for a repeated measures experiment, to compare the effects of each UAS contingency scenario to a baseline scenario.

6 Results

Simulation results are reported for all three configurations. Each configuration was considered independently, and therefore, separate analyses were conducted for each of the three configurations of interest.

For each configuration, a repeated- measures one-way ANOVA was conducted to compare the effects of each UAS contingency scenario to a baseline scenario (no UAS, no contingency events). Since each configuration was considered and analyzed separately, a unique baseline scenario was created for each configuration, resulting in three separate analyses. Furthermore, although viable, comparisons between contingency events were outside the scope of the research questions, and thus are not presented. Data from the experiment is available for future analysis.

Once the ANOVA was conducted for each of the measures, if there were any significant main effects, the Tukey Honestly Significant Difference (HSD) post-hoc test was conducted to determine which specific conditions had the significant differences to the baseline condition for the particular measure of concern.

Within each configuration, it is significant to note that all controller positions for the configuration of interest were simulated and staffed by controllers from NCT in an effort to maintain emulation of realistic operations within their representative sectors. All sectors and positions were subjects of study and part of the analyses. To focus on the goals of the research, the results are presented from the position/sector that was most impacted by the specific event(s) of interest.

Lastly, extensive data was collected through this simulation, and for the purposes of conciseness, not all results are reported in this section. Comprehensive summaries of all results can be found in Appendix G through Appendix Q.

6.1 Configuration 1 (Arrival): Grove and Grove Handoff

For Configuration 1, the Grove sector was studied to evaluate the impact of the UAS contingency events. The role of the Grove HO position was to provide general assistance to the Grove sector radar controller. The Grove HO responsibilities included: inter- and intra-facility coordination, release of departures, coordination of arrival information, flight strip management, and general sector workload management. Results are presented from the Grove HO and/or Grove sector radar controller position(s) best representing the effects of the contingency operation.

For Configuration 1, the three arrival scenarios are as follows:

- Baseline, lost link (during arrival)
- Lost comm (loss of two-way radio communications, but the control link is maintained)
- Fly-away (lost link, and the UA does not follow the pre-programmed lost-link profile)

The descriptions of these scenarios can be found in Section 4.7.1, Airspace Configuration 1 and Detailed Traffic Scenarios.

6.1.1 Safety Data

Safety measures such as MAC, NMAC, and LOS were collected in order to evaluate the impact of UAS contingency operations on system safety. The overall result on system safety was that no significant effects of the contingency events on safety were observed. No MACs or NMACs occurred in any scenario. The effect of contingency events on the losses of separation was not significant (F (3, 33) = 1.83, p = 0.16). Lack of a significant difference between the baseline condition and the contingency operation conditions could indicate that there was no measurable effect of UAS contingency operations on system safety, and that the controllers were able to maintain safety despite the adverse events as simulated. Results of LOS data are shown in Figure 6-1.

Figure 6-1 Configuration 1, Mean (M) Number of Losses of Separation (Grove)

6.1.2 ATC Data

A variety of data was collected to evaluate the impact of UAS contingency operations on the controller. This evaluation was performed primarily through the Post-Scenario Questionnaire, in which participants were asked to subjectively assess their workload, SA, and overall experiences during the scenario just completed. In addition, all PTT data was recorded, which includes the number of times controllers and simulation pilots keyed their microphones to make radio transmissions, the radio frequency that was used, and the duration of each transmission.

6.1.2.1 Workload

Workload was evaluated through the post-scenario questionnaire, which contained questions regarding the six dimensions of the NASA-TLX rating scale (mental demand, physical demand, temporal demand, performance, effort, and frustration). In addition, controllers were queried on their overall level of workload, as well as their level of workload due to communications with pilots or the front line manager. Lastly, the WAK was used to provide an additional measure of workload using a real-time technique as controllers executed the simulation traffic scenarios.

The results from the NASA-TLX workload ratings for all conditions from the Grove Handoff position are shown in Figure 6-2.

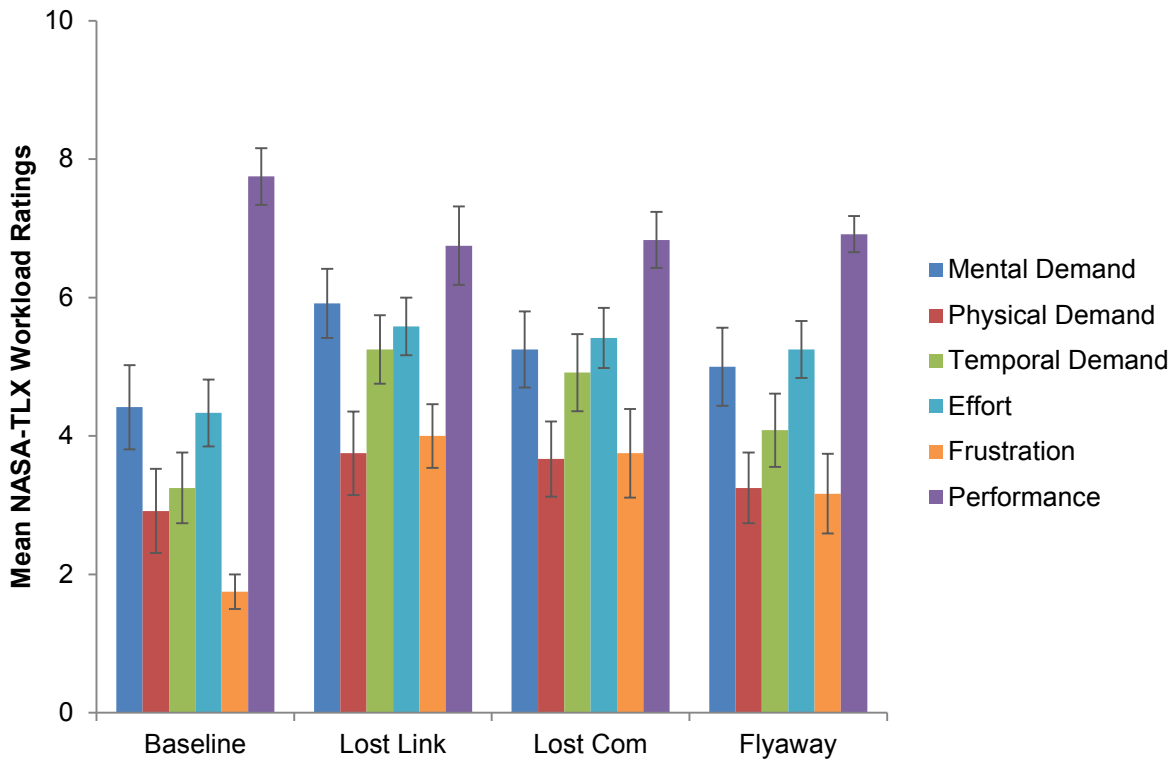

Figure 6-2 Configuration 1, Mean NASA-TLX Ratings (Grove HO)

Analyses showed that the contingency operations had a significant effect on the NASA-TLX workload scale dimensions of mental demand (F (4, 44) = 3.07, $p < 0.05$), temporal demand (F (4, 44) = 2.79, $p < 0.05$), performance (F (4, 40) = 2.94, $p < 0.05$), and effort (F (4, 44) = 2.77, $p < 0.05$). Tukey's post-hoc test showed that the mental demand rating for the lost-link condition was significantly higher than the baseline condition, the effort rating for the lost-link and lost-comm conditions were significantly higher than the baseline, and the frustration rating for the lost link, lost comm, and fly-away conditions were significantly higher than the baseline condition. Performance is rated inversely from the other dimensions (high ratings indicate assessment of good performance). Therefore, as shown, performance was rated higher in the baseline condition than the contingency operations conditions. These significant

differences indicate that the complications caused by the UAS encountering these events could have resulted in an overall higher level of workload for the controllers. And while not showing statistically significant differences, the other dimensions show a trend towards higher levels of workload, as compared to the baseline condition.

Furthermore, Figure 6-3 illustrates that a portion of this elevated workload could be attributed to the increased amounts of coordination between the controller and the front line manager that was induced by the contingency operation. For the Grove radar controller, the results were significantly higher in the lost-comm condition. And as would be expected, the Grove handoff position experienced the bulk of the workload due to this increased coordination. Figure 6-3 depicts the ratings by the Grove handoff position.

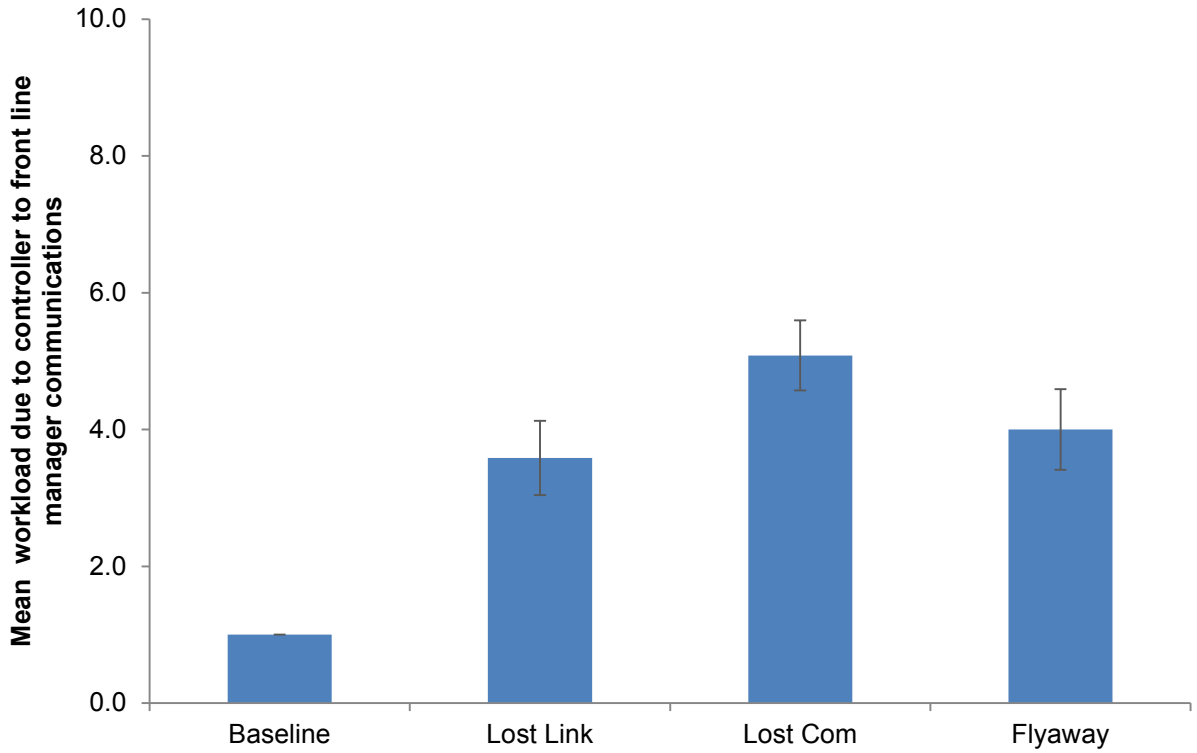

Figure 6-3 Configuration 1, Mean Workload Ratings (Grove HO)

(Due to ATCS-to-FLM Communications)

Analyses showed that contingency events had a significant effect on the Grove HO's workload due to controller-to-front line manager communications (F (3, 27) = 19.70, $p < 0.05$). Tukey's post-hoc test showed that the workload due to controller-to-front line manager communications in the lost-link condition (*Mean (M) = 3.9, Standard Error (SE)* = 0.5), the lost-comm condition (M = 5.4, SE = 0.5), and fly-away condition (M = 4.3, SE = 0.6) were significantly higher than the baseline condition (M = 1.0, SE = 0.0).

6.1.2.2 Post-Scenario Questionnaire Data

In addition to the effect on controller workload, the Post-Scenario Questionnaire data reveals further insights into the effects of the UAS contingency operations on the controller. Effects include a degraded sense of safety (shown for the Grove sector in Figure 6-4), and a degraded assessment of efficient aircraft operations (shown for Grove HO in Figure 6-5).

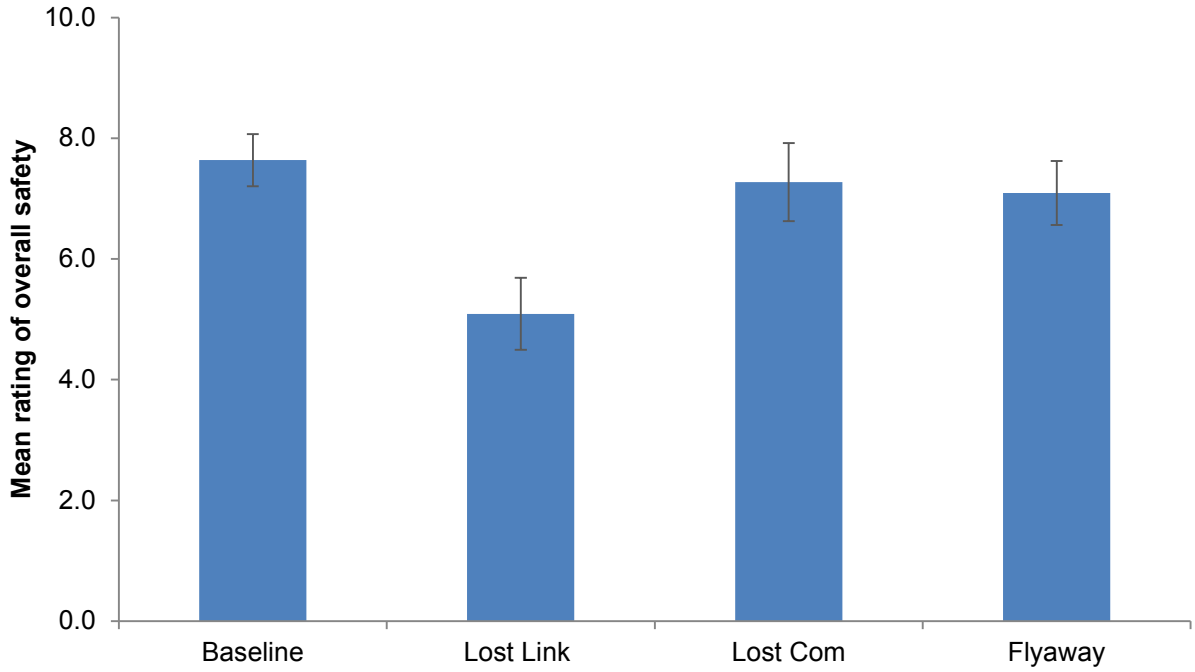

Figure 6-4 Configuration 1, Mean Self-assessment Ratings of Overall Safety (Grove)

The complications caused by these contingency events resulted in a degraded self-assessment of overall safety on the part of the Grove radar controller. Analyses showed that contingency events had a significant effect on the controller's sense of safety (F (3, 33) = 5.68, $p < 0.05$). Tukey's post-hoc test showed that the safety rating of the lost-link condition (M = 5.3, SE = 0.6) was significantly lower than the baseline condition (M = 7.8, SE = 0.4). However, as our results from Section 6.1.1 showed, despite this sense of degraded safety, the controllers were able to maintain safety by placing prioritization on safety, even though it could have an adverse effect on their ability to move aircraft efficiently through the sector, which is shown in Figure 6-5.

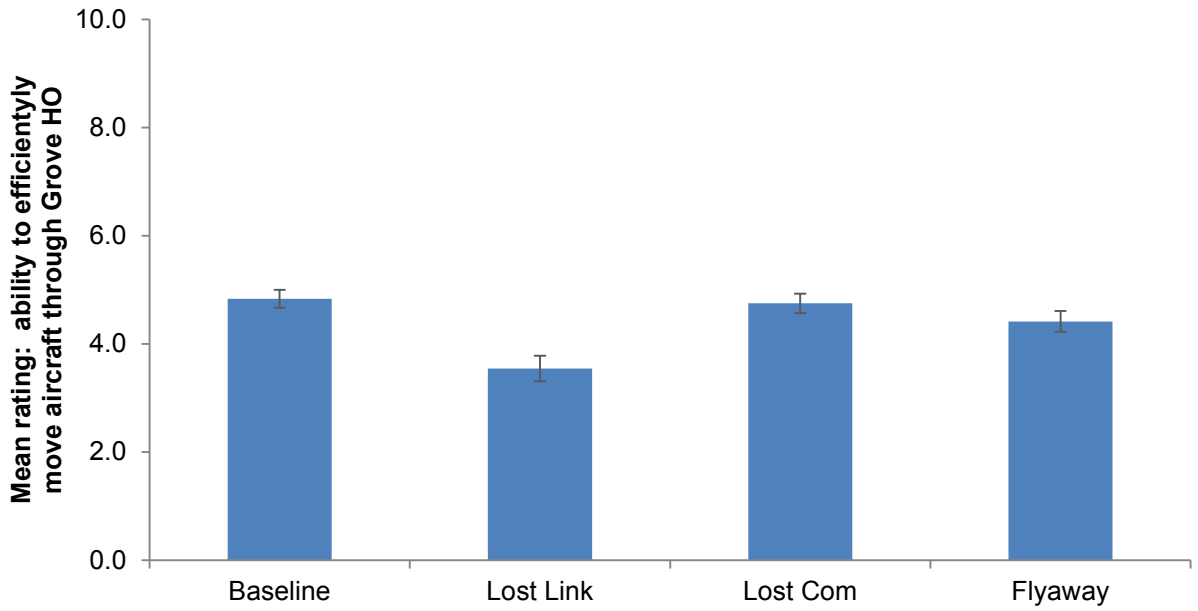

Figure 6-5 Configuration 1, Mean ATCS Rating of Ability to Move AC Efficiently (Grove HO)

Analyses showed that contingency events had a significant effect on the handoff controllers' subjective assessment of their ability to move aircraft efficiently through the sector (F (3, 30) = 7.97, $p < 0.05$). Tukey's post-hoc test showed that the self-assessed rating of this efficiency in the lost-link condition (M = 3.6, SE = 0.2) was significantly lower than the baseline condition (M = 4.8, SE = 0.2), indicating that controllers sensed that efficiency was degraded due to the contingency operations.

The comprehensive list of results from the Post-Scenario Questionnaire for both the Grove radar controller position and the Grove handoff position can be found in Appendix G and Appendix H, respectively.

6.1.3 Efficiency Data

The controllers' subjective assessments of degraded efficiency may be supported through analyses of the number of arrival delays, as this configuration was the arrival configuration.

While the effect of contingency events on the number of arrival delays was not significant (F (3, 33) = 1.51, p = 0.23), the plot in Figure 6-6 indicates a potential difference of the lost link arrival condition on arrival delays. Although it was not statistically significant, there is an observable difference between the number of arrival delays for the baseline condition (M = 0.3, SE = 0.1) compared to the lost-link condition (M = 1.3, SE = 0.6).

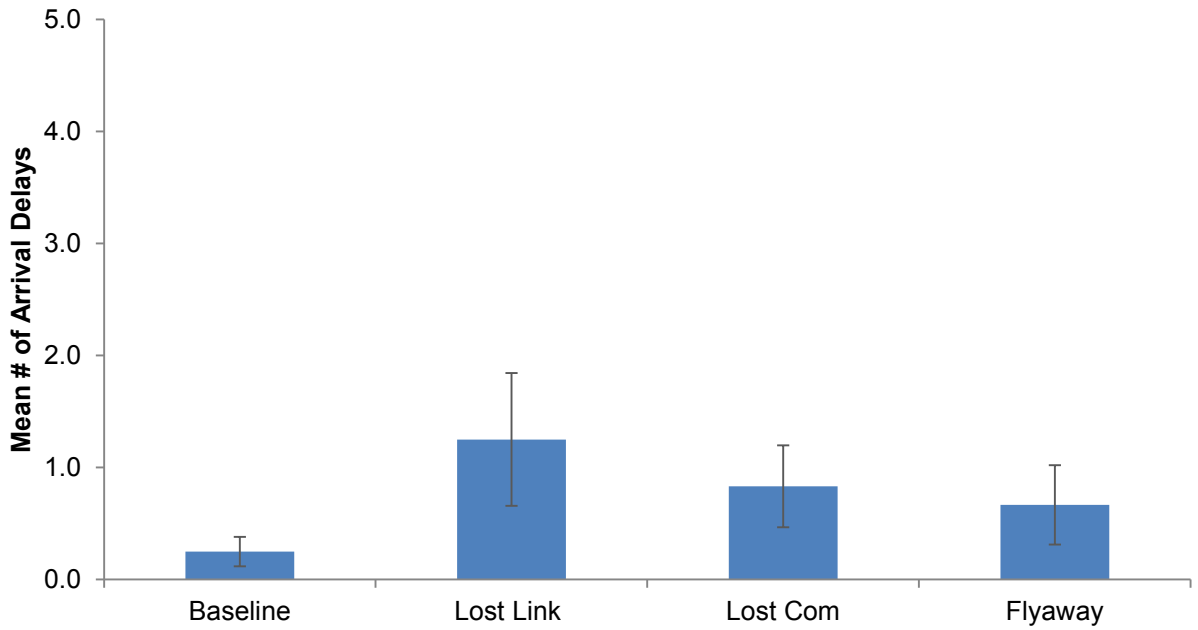

Figure 6-6 Configuration 1, Mean Number of Arrival Delays (Grove)

Indication of reduced efficiency is further supported through the results from the following two configurations.

6.2 Configuration 2 (Departure): Richmond and Sutro

The results for this departure configuration are presented for the Richmond sector, which was the primary sector impacted by UAS contingency operations. The results for the Sutro sector can be found in Appendix J.

The priority scenarios for Configuration 2 were lost link-cruise (lost link during initial cruise), lost link-departure (lost link during departure), flight termination, and engine failure. The descriptions of these scenarios can be found in Section 4.7.2, Airspace Configuration 2 and Detailed Traffic Scenarios.

In addition to these core scenarios, for this configuration, there was a target of opportunity for additional runs. Therefore, a sub-analysis of this configuration was conducted with a smaller sample size, and labeled "Configuration 2A." The scenarios conducted for this sub-analysis were lost link-cruise, lost link-departure, flight termination, engine failure, lost link-multiple, lost comm and fly-away. As the sample size for this sub-analysis was smaller than the analysis for the core scenarios, the results for these scenarios are provided as a supplement to the primary findings, and can be found in Appendix L.

6.2.1 Safety Data

A variety of safety measures were collected in order to evaluate the impact of UAS contingency operations on system safety, including MAC, NMAC and LOS. Overall, there were no significant effects of the contingency events on safety. No MACs or NMACs occurred in any

scenario, and the results pertaining to loss of separation for the Richmond sector is provided in Figure 6-7.

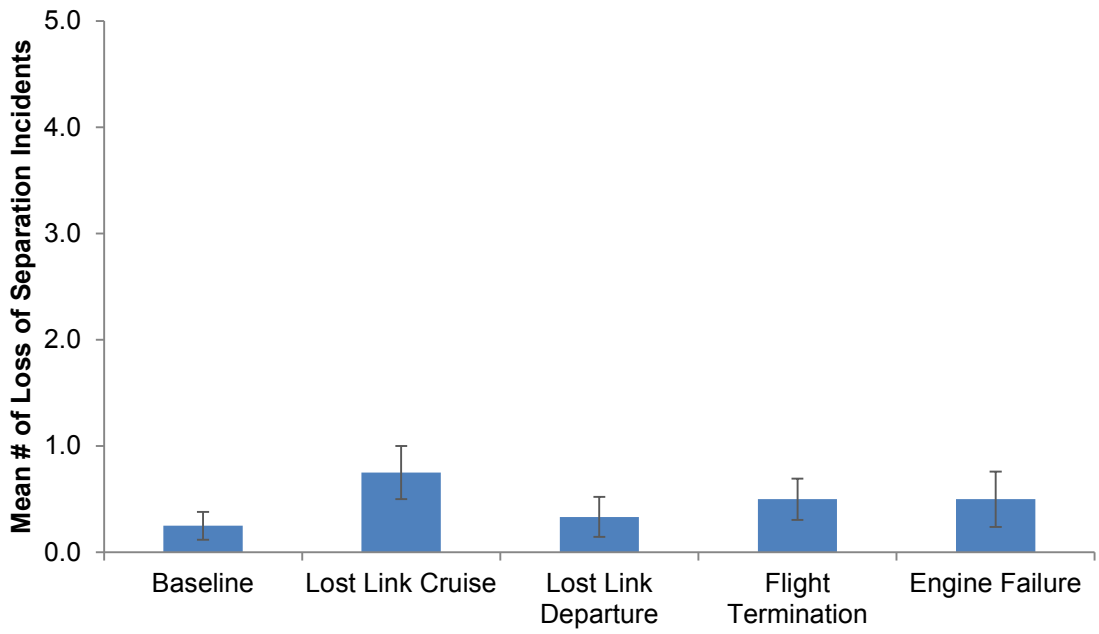

Figure 6-7 Configuration 2, Mean Loss of Separation (Richmond)

The effect of contingency events on incidence of loss of separation was not significant (F (4, 44) = 1.04, p = 0.40). This lack of a significant difference between the baseline condition and the contingency conditions could indicate that there was no measurable effect of the UAS contingency operations on system safety, and that the controllers were able to maintain safety despite these adverse events.

6.2.2 ATC Data

A variety of data was collected to evaluate the impact of UAS contingency operations upon the controller. This was primarily performed through the post-scenario questionnaire, in which participants were asked to subjectively assess their workload, SA, and overall experiences during the particular scenario just completed. In addition, all PTT data was recorded, which includes the number of times controllers and simulation pilots keyed their microphones to make radio transmissions, the radio frequency that was used, and the duration of each transmission.

6.2.2.1 Workload

Workload was measured through the post-scenario questionnaire, which contained questions related to the six dimensions of the NASA-TLX ratings scale. In addition, controllers were queried on their overall level of workload, as well as their level of workload due to communications. Lastly, the WAK was used to provide an additional measure of workload using a real-time technique as controllers performed the traffic scenarios.

The results from the NASA-TLX workload ratings for all conditions are shown in Figure 6-8.

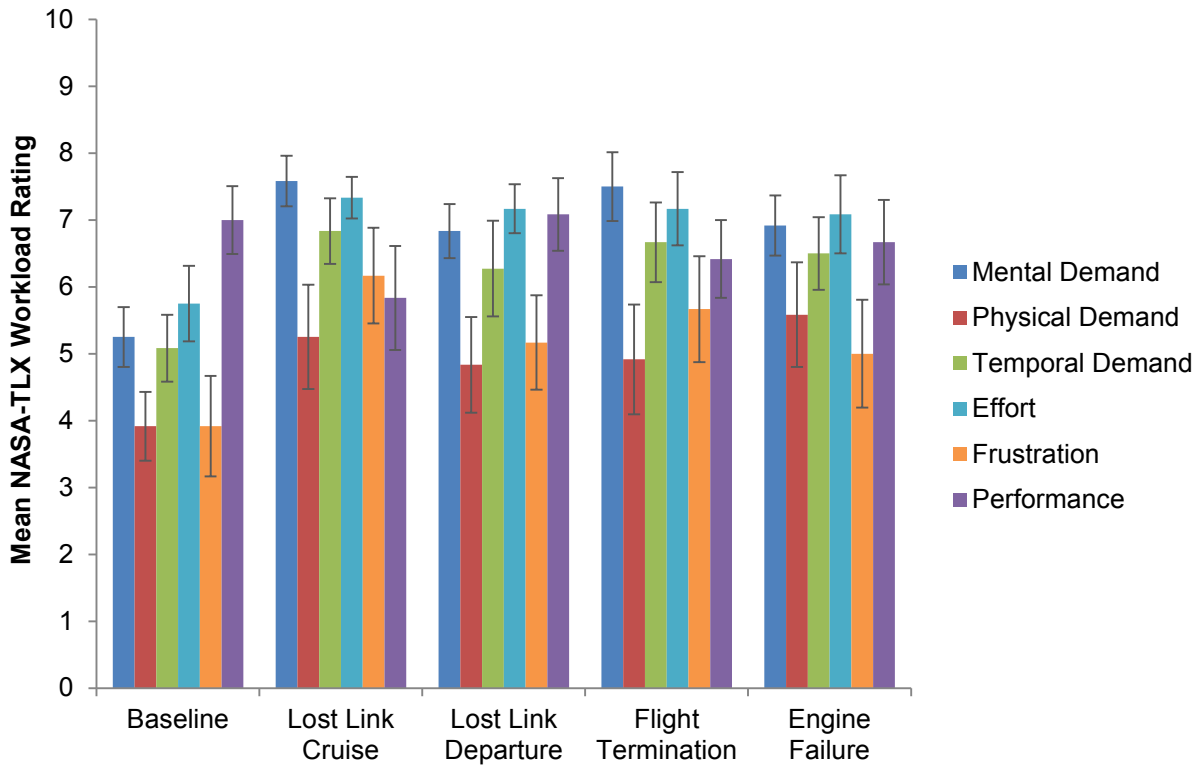

Figure 6-8 Configuration 2, Mean NASA-TLX Ratings (Richmond)

Analyses showed that the contingency events had a significant effect on the NASA-TLX workload scale dimensions of mental demand (F (4, 44) = 8.71, $p < 0.05$), physical demand (F (4, 44) = 4.90, $p < 0.05$), temporal demand (F (4, 40) = 2.90, $p < 0.05$), effort (F (4, 44) = 3.17, $p < 0.05$), and frustration (F (4, 44) = 3.27, $p < 0.05$). Tukey's post-hoc test showed that the ratings for the lost link-cruise condition, for all of these dimensions, were significantly higher than the baseline condition, indicating that the complications caused by the lost link occurring during the cruise phase resulted in an overall higher level of workload for the controllers.

This indication of elevated workload is further supported by the WAK rating results, shown in Figure 6-9.

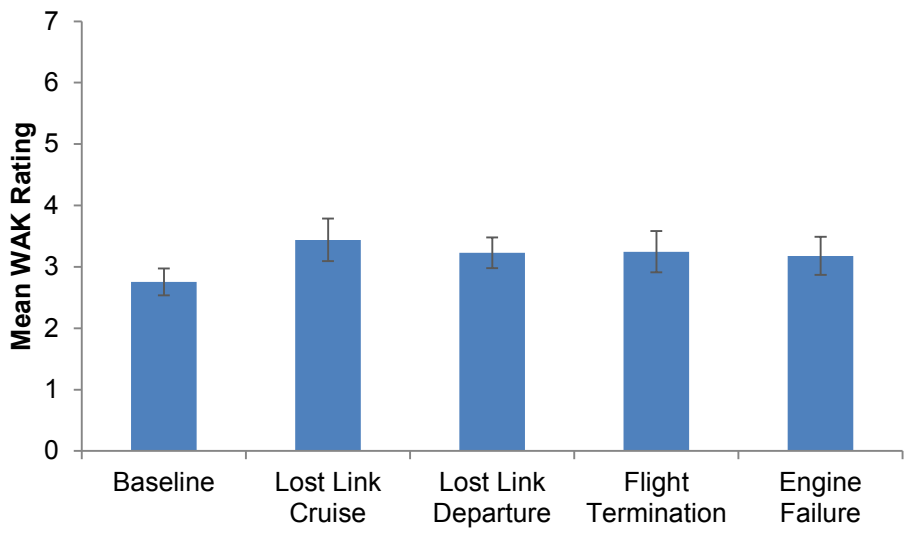

Figure 6-9 Configuration 2, Mean WAK Ratings (Richmond)

Analyses showed that contingency events had a significant effect on mean WAK rating (F (4, 40) = 2.58, $p < 0.05$). Tukey's post-hoc test showed that the WAK rating of the lost link-cruise condition (M = 3.4, SE = 0.3) was significantly higher than the baseline condition (M = 2.75, SE = 0.2), indicating again that the complications caused by the lost link during the cruise phase resulted in a higher level of workload for the controllers. Although overall ratings are on the lower end of the scale, the demonstrated relative increase is still to be noted.

Furthermore, Figure 6-10 shows that a portion of this increased workload could be attributed to the increased controller-to-pilot communications that was caused by the contingency event.

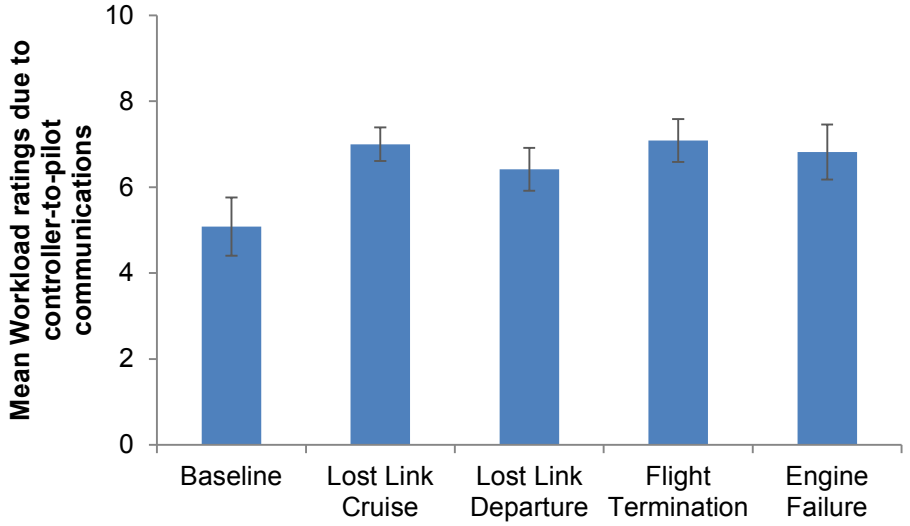

Figure 6-10 Configuration 2, Mean Workload Rating Due to ATCS-to-Pilot Comm (Richmond)

Analyses showed that contingency events had a significant effect on the workload due to controller-to-pilot communications (F (4, 40) = 2.61, $p < 0.05$). Tukey's post-hoc test showed that the workload due to controller-to-pilot communications in the flight termination condition (M = 7.4, SE = 0.5) was significantly higher than the baseline condition (M = 5.2, SE = 0.7). While not significantly higher, the workload due to controller-to-pilot communications in the lost link-cruise condition (M = 7.2, SE = 0.4) was notably highly than the baseline condition, as well.

As stated, the complications caused by these lost-link events would necessitate greater amounts of communication between controllers and pilots in order to maintain safety within the sector. Analysis of the Push-To-Talk transmission data, as presented in Section 6.2.2.2, further confirms these indications.

6.2.2.2 Push-To-Talk (PTT) Transmission Data

All PTT transmission data was collected through the TGF software, including the number of times the controllers or pilots keyed their microphones to make radio transmissions, the frequency that was used, and the duration of each transmission.

Controller workload is shown to have increased due to the increase in communications induced by contingency operations. This quantifiable increase in the number of transmissions is shown in Figure 6-11.

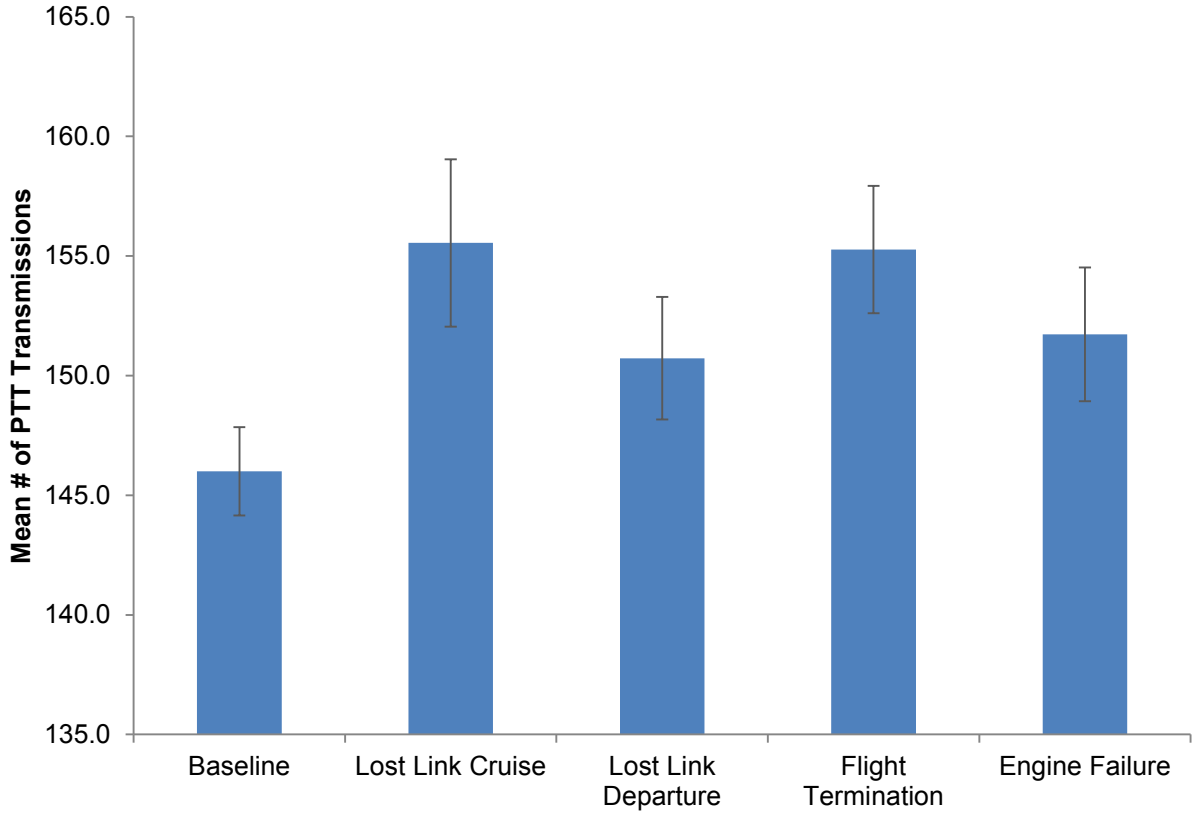

Figure 6-11 Configuration 2, Mean Number of PTT Transmissions (Richmond)

Analyses showed that contingency events had a significant effect on the average number of PTT transmissions (F (4, 40) = 2.76, $p < 0.05$). Tukey's post-hoc test showed that the average number of transmissions in the lost link-cruise condition (M = 155.6, SE = 3.5) was significantly higher than the baseline condition (M = 146.0, SE = 1.8).

6.2.2.3 Post-Scenario Questionnaire Data

In addition to the effect on controller workload, the post-scenario questionnaire data reveals further insights into the effects of the UAS contingency operations on the controller. Effects include degraded SA (shown in Figure 6-12), degraded assessment of safe and efficient aircraft operations, as well as other effects. A summary of the statistically significant effects from the post-scenario data is presented in Table 6-1 (significant results are shown in bold).

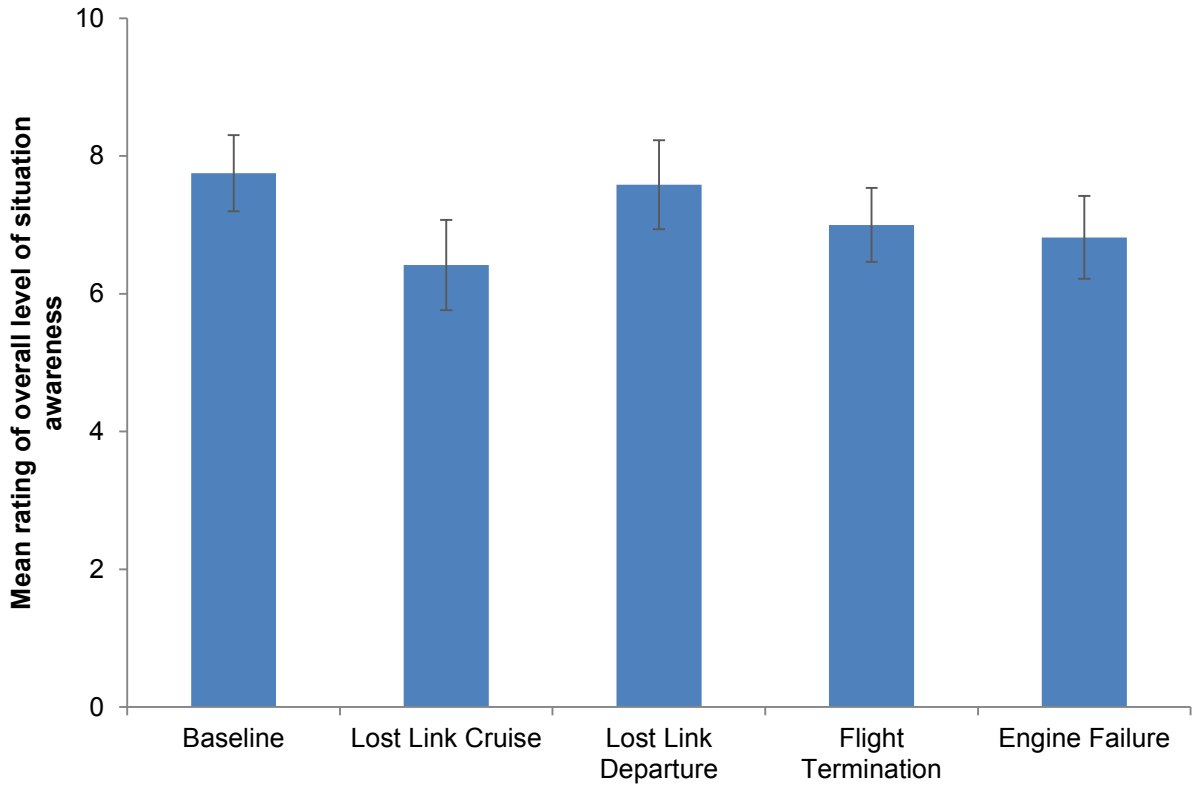

Figure 6-12 Configuration 2, Mean Rating of Overall Level of SA (Richmond)

Analyses showed that contingency events had a significant effect on the controllers' assessment of their overall level of SA (F (4, 40) = 4.03, $p < 0.05$). Tukey's post-hoc test showed that the average SA rating in the lost link-cruise condition (M = 6.6, SE = 0.7) was significantly lower than the baseline condition (M = 7.7, SE = 0.6), indicating that the lost link during the cruise phase contributed to a degraded level of SA for the controller.

Table 6-1 summarizes some relevant results from the post-scenario questionnaire data. Comprehensive results can be found in the Appendix.

Table 6-1 Summary of Post-Scenario Questionnaire Data

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Termination	Engine Failure
NASA-TLX, Mental Demand	5.25	**7.58**	**6.83**	**7.50**	**6.92**
NASA-TLX, Physical Demand	3.92	**5.25**	4.83	4.92	**5.58**
NASA-TLX, Temporal Demand	5.09	**6.91**	6.27	6.64	6.27
NASA-TLX, Performance	7.00	5.83	7.08	6.42	6.67
NASA-TLX, Effort	5.75	**7.33**	7.17	7.17	7.08
NASA-TLX, Frustration	3.92	**6.17**	5.17	5.67	5.00
Overall Safety	8.00	**6.45**	7.64	6.73	6.91
Ability to move aircraft efficiently through the sector	5.64	**4.18**	4.91	4.91	5.00
Overall Workload	6.25	**7.92**	**7.33**	**7.75**	**7.33**
Workload due to controller-to-pilot communications	5.18	7.18	6.73	**7.36**	6.82
Workload due to controller-to-front line manager communications	1.00	1.55	1.45	**2.18**	1.64
Overall level of SA	7.73	**6.64**	7.55	6.91	6.82
SA for detecting aircraft conflicts	7.82	**6.45**	7.45	**6.73**	7.09
Overall difficulty of the scenario	5.73	**7.73**	6.91	**7.36**	**7.27**

6.2.3 Efficiency Data

Using the NIEC's extensive data collection system, recorded aircraft track and status information was used to evaluate the impact on system efficiency (Buckley, DeBaryshe, Hitchner, & Kohn, 1983; Stein & Buckley, 1992). In addition, the number of times that controllers executed an HFR, and the number of departure and arrival delays were tallied. These measures were also used to evaluate the effect of UAS contingency operations on system efficiency.

6.2.3.1 Flight Time

The aircraft track data was used to determine flight times and distances for the sector in each scenario. Notionally, if a contingency operation requires reroutes for other aircraft, the result would be longer flight times and distances flown in the sector. Such effects were indeed observed, and as an example, the results in Figure 6-13 show the average flight times that aircraft spent in the sector.

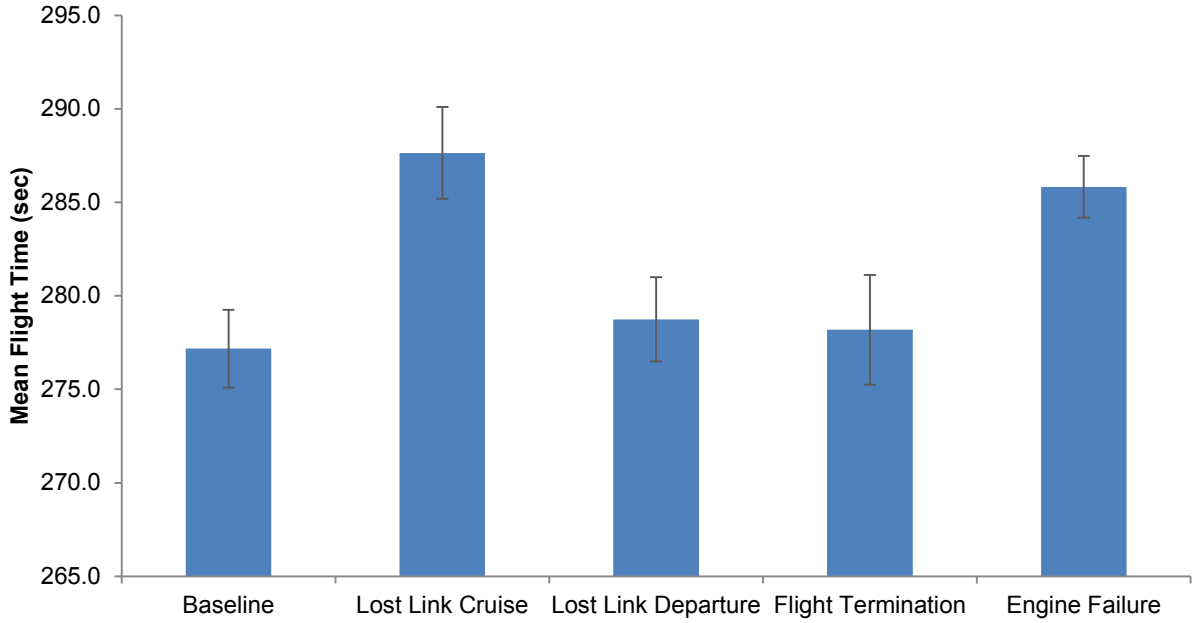

Figure 6-13 Configuration 2, Mean Flight Time (Richmond)

Analyses showed that contingency operations had a significant effect on mean flight time (F (4, 40) = 6.84, $p < 0.05$). Tukey's post-hoc test showed that the mean flight time during the lost link-cruise condition (M = 287.6 sec, SE = 2.5) and the engine failure condition (M = 285.5 sec, SE = 1.7) were significantly higher than the baseline condition (M = 277.2 sec, SE = 2.1), indicating that these two contingency events greatly affected the airspace efficiency by causing flights to spend longer average time in the sector.

6.2.3.2 Delay

In addition to flight time and distance, arrival and departure delays were measured to evaluate efficiency. Examining the number of delays, as well as the number of times that controllers initiated an HFR, can provide insights into how controllers managed the particular contingency operation, and the corresponding effect on system efficiency.

Figure 6-14 shows the average number of HFRs initiated per scenario.

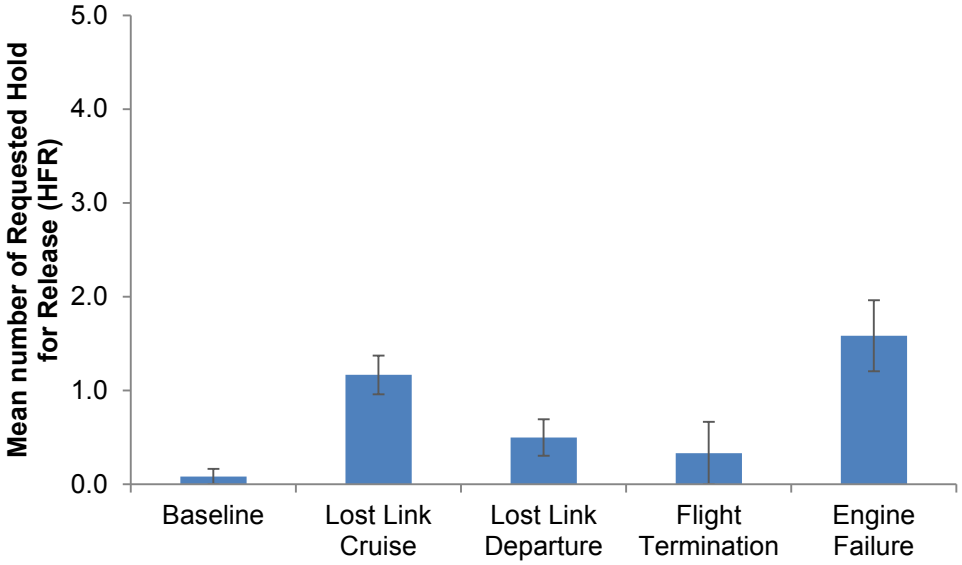

Figure 6-14 Configuration 2, Mean Number of Requested HFRs (Richmond)

Analyses showed that contingency operations had a significant effect on the number of HFRs (F (4, 44) = 6.85, $p < 0.05$). Tukey's post-hoc test showed that the mean number of HFRs initiated during the lost link-cruise condition (M = 1.2, SE = 0.2) and the engine failure condition (M = 1.6, SE = 0.4) were significantly higher than the baseline condition (M = 0.1, SE = 0.1), indicating the potential impact on efficiency due to these contingency operations.

This impact is captured in Figure 6-15, which shows the average number of departure delays that occurred per scenario.

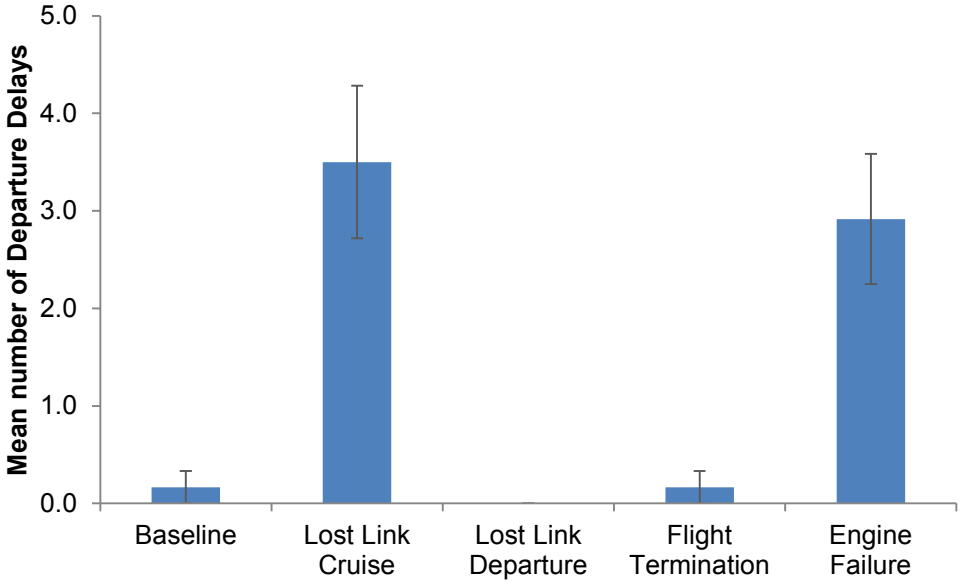

Figure 6-15 Configuration 2, Mean Number of Departure Delays (Richmond)

Analyses showed that contingency operations had a significant effect on the number of departure delays, (F (4, 44) = 16.22, $p < 0.05$). Tukey's post-hoc test showed that the mean number of departure delays that occurred during the lost link-cruise condition (M = 3.5, SE = 0.8) and the engine failure condition (M = 2.9, SE = 0.7) were significantly higher than the baseline condition (M = 0.2, SE = 0.2), indicating the potentially reduced efficiency caused by these contingency operations. As these events occur and disrupt the normal flow of traffic, controllers needed to enact commonly used tools to delay outgoing traffic in order to maintain safe operations. As such, the analyses indicate the lack of a significant effect on system safety, but they reveal a significant effect on system efficiency.

Of note is the lack of significant differences for the lost link-departure and flight termination scenarios, not only with regard to efficiency, but with controller assessments as well. This further supports the notion that not all contingency events are equal. The lost link-departure scenario was anticipated to be a less disruptive lost-link event compared to the lost link-cruise scenario, and the results support this expectation. As this configuration's scenarios demonstrated, there can be large differences even among lost link scenarios, depending on the lost link procedure, where the loss of link occurs, the loiter point, and a variety of other factors. This has implications to establish regulations for UAS contingency operations, which will be further discussed in the Section 8, Recommendations.

6.3 Configuration 3 (Arrival): Mulford and Grove

For Configuration 3, the impact of the UAS contingency event was similar for both sectors. Therefore, the results are shown for the representative sector that most adequately demonstrates the impact of these contingency events. Comprehensive results for Mulford and Grove in this configuration can be found in Appendix O and Appendix P, respectively.

For Configuration 3, the scenarios conducted were lost link, lost comm, fly-away, and emergency divert. The descriptions of these scenarios can be found in Section 4.7.3, Airspace Configuration 3 and Detailed Traffic Scenarios.

6.3.1 Safety Data

Safety measures such as MAC, NMAC, and LOS were collected in order to evaluate the impact of UAS contingency operations on system safety. The overall result on system safety is that there were no significant effects of the contingency event on safety. No MACs or NMACs occurred in any scenario, and a very minimal number of LOSs occurred, as shown by the results in Figure 6-16. These results are from the Mulford sector. Similar results for the Grove sector are found in Appendix P.

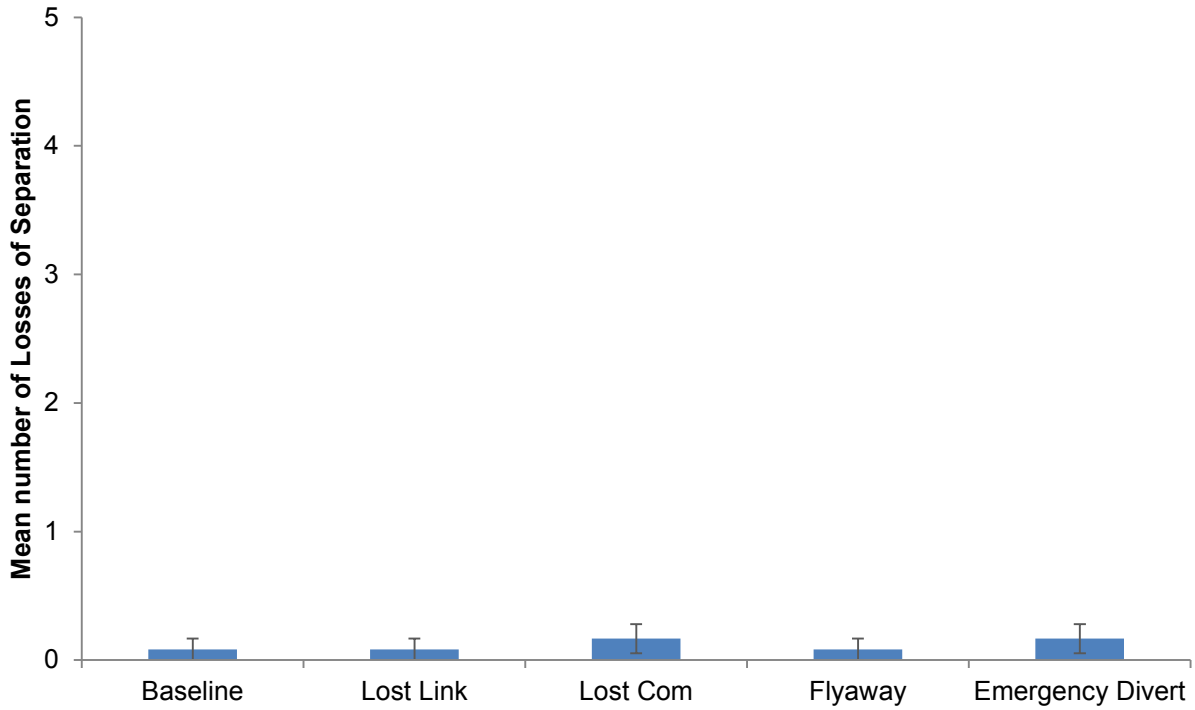

Figure 6-16 Configuration 3, Mean Loss of Separation (Mulford)

The effect of contingency events on incidents of loss of separation was not significant, (F (4, 44) = 0.22, p = 0.93). This lack of a significant difference between the baseline condition and the contingency conditions could indicate the ability of the controllers to maintain safety through the events, since there was no measurable effect of the contingency events on system safety.

6.3.2 ATC Data

Data was collected, primarily through the post-scenario questionnaire, to evaluate the impact of UAS contingency operations upon the controller. The controllers were asked to subjectively assess their workload, SA, and overall experiences during the particular scenario that they had just completed.

6.3.2.1 Workload

Workload was measured through the post-scenario questionnaire and the real-time WAK ratings. The questionnaire contained questions related to the six dimensions of the NASA-TLX ratings scale, as well as questions regarding their overall level of workload and their workload due to communications. The WAK was used to provide an additional measure of workload using a real-time technique as controllers performed the traffic scenarios.

The results from the NASA-TLX workload ratings for all conditions for the Mulford sector are shown in Figure 6-17.

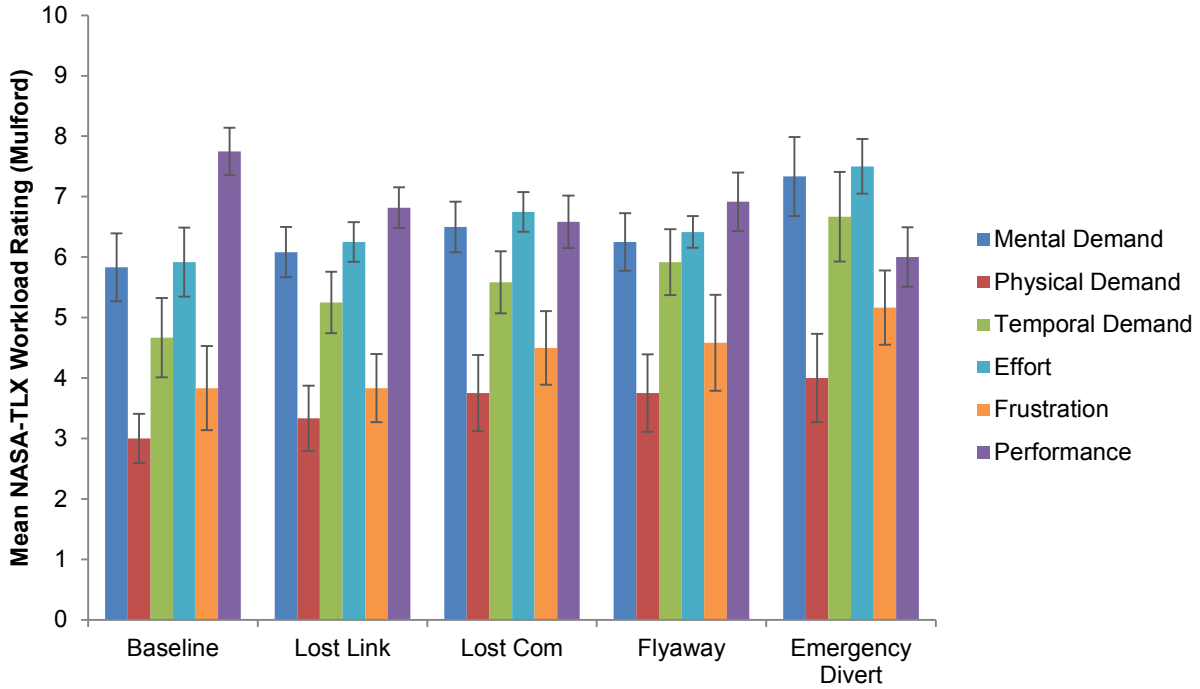

Figure 6-17 Configuration 3, Mean NASA-TLX Ratings (Mulford)

Analyses showed that the contingency operations had a significant effect on the NASA-TLX workload scale dimensions of mental demand (F (4, 44) = 3.07, $p < 0.05$), temporal demand (F (4, 44) = 2.79, $p < 0.05$), performance (F (4, 40) = 2.94, $p < 0.05$), and effort (F (4, 44) = 2.77, $p < 0.05$). Tukey's post-hoc test showed that the ratings for the emergency divert condition, for all of these dimensions, were significantly higher than the baseline condition, indicating that the complications caused by the UAS encountering an emergency divert situation resulted in an overall higher level of workload for the controllers, and a reduction in their self-assessment of performance. While not showing statistically significant differences, the other dimensions show a trend towards higher levels of workload, as compared to the baseline condition.

Furthermore, as shown in Figure 6-18, a portion of this elevated workload could be attributed to the contingency event causing increased amounts of coordination between the controller and the front line manager. Figure 6-18 provides ratings by the Mulford controllers, which was the sector in which the event initially occurred.

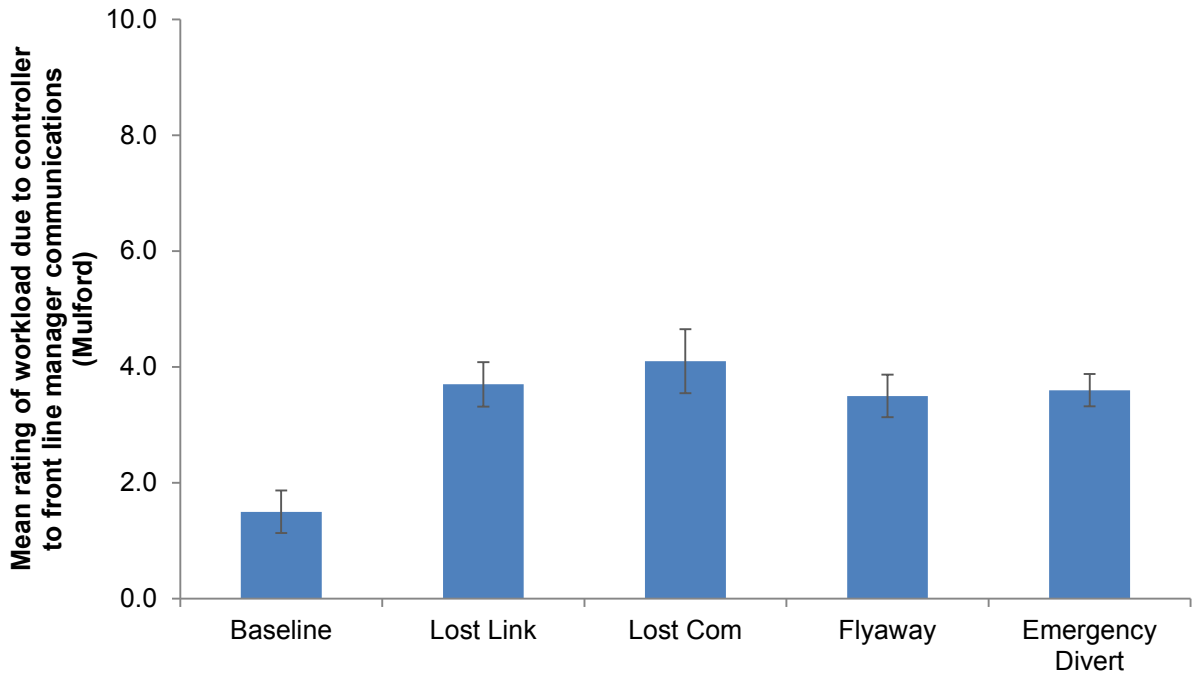

Figure 6-18 Configuration 3, Mean Workload Rating Due to ATCS-to-FLM Comms (Mulford)

Analyses showed that contingency events had a significant effect on the workload due to controller-to-front line manager communications (F (4, 36) = 8.24, $p < 0.05$). Tukey's post-hoc test showed that the workload due to controller-to-front line manager communications in the lost-link condition (M = 3.7, SE = 0.4), the lost-comm condition (M = 4.1, SE = 0.6), fly-away condition (M = 3.5, SE = 0.4), and emergency divert condition (M = 3.6, SE = 0.3) was significantly higher than the baseline condition (M = 1.5, SE = 0.4).

6.3.2.2 Push-To-Talk (PTT) Transmission Data

All PTT transmission data was collected through the TGF software, including the number of times the controllers or pilots keyed their microphones to make radio transmissions, the frequency that was used, and the duration of each transmission.

A portion of the increased controller workload was shown to potentially be due to the increased coordination with the front line manager. Another portion of the increased workload was shown to potentially be due to the increased communications with pilots induced by contingency operations. This increase in the number of transmissions for the Grove sector is shown in Figure 6-19.

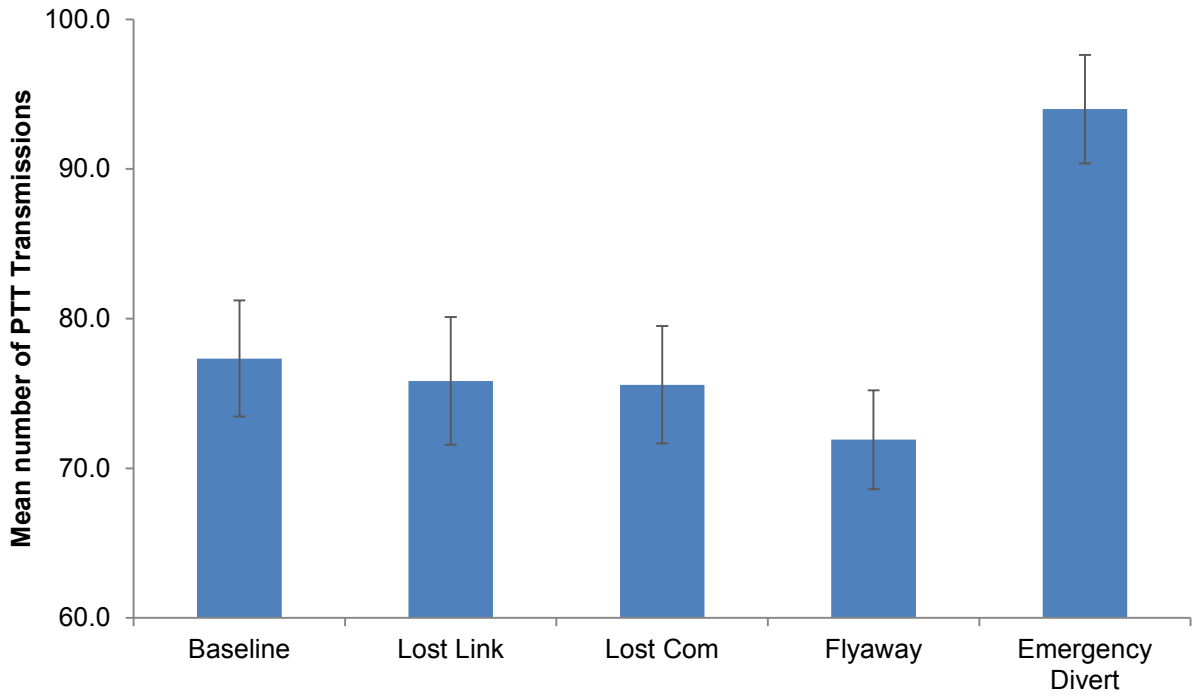

Figure 6-19 Configuration 3, Mean Number of PTT Transmissions (Grove)

Analyses showed that contingency events had a significant effect on the number of PTT transmissions (F (4, 40) = 6.92, $p < 0.05$). Tukey's post-hoc test showed that the average number of transmissions in the emergency divert condition (M = 94.0, SE = 3.6) was significantly higher than the baseline condition (M = 78.6, SE = 3.9).

6.3.2.3 Post-Scenario Questionnaire Data

In addition to the effect on controller workload, the post-scenario questionnaire data reveals further insights into the effects of the UAS contingency operations on the controller. Effects include degraded SA (shown for the Grove sector in Figure 6-20), degraded assessment of efficient aircraft operations, as well as other effects. A summary of the statistically significant effects from the post-scenario data for both sectors is presented in Table 6-2 and Table 6-3.

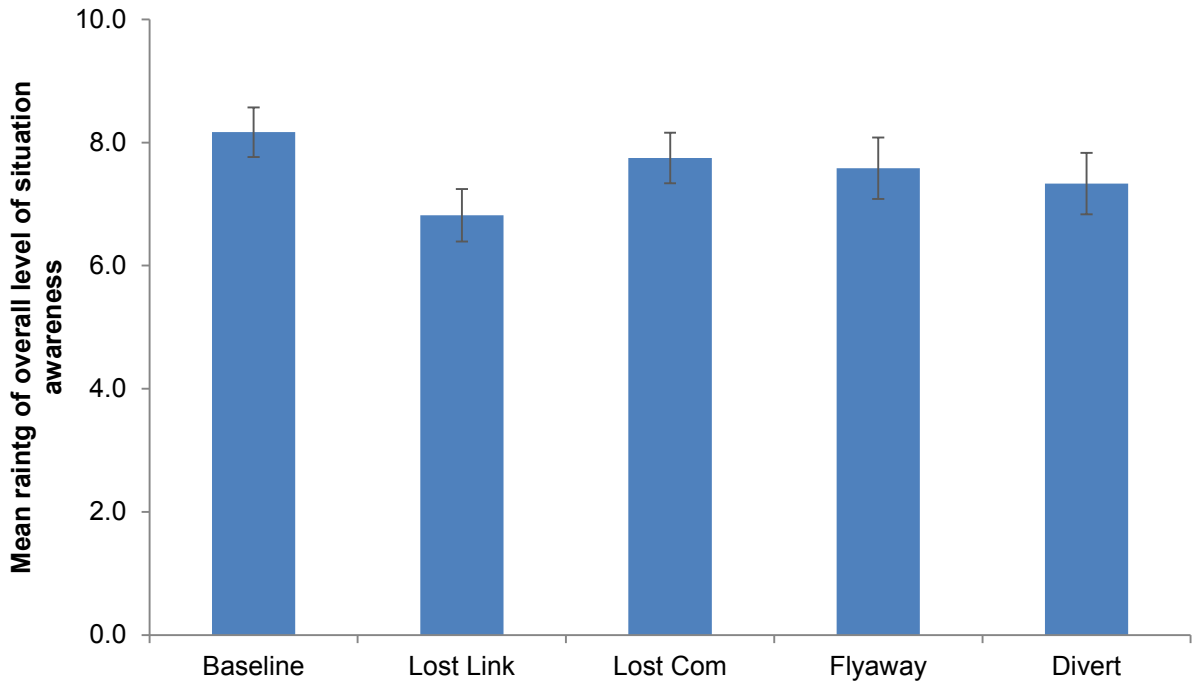

Figure 6-20 Configuration 3, Mean Rating of Overall Level of SA (Grove)

Analyses showed that contingency events had a significant effect on the Grove controllers' assessment of their overall level of SA (F (4, 40) = 2.78, $p < 0.05$). Tukey's post-hoc test showed that the average rating of SA in the lost link-cruise (M = 6.8, SE = 0.4) was significantly lower than the baseline condition (M = 8.0, SE = 0.4), indicating that the UAS undergoing lost link during the cruise phase contributed to a degraded level of SA of the controller.

The complications caused by these contingency events notionally would necessitate greater amounts of communication between controllers and front line managers to help coordinate and maintain safety within the sector. The controllers placed priority on safety, even though it could have an adverse effect on their ability to move aircraft efficiently through the sector, which is shown in Figure 6-21.

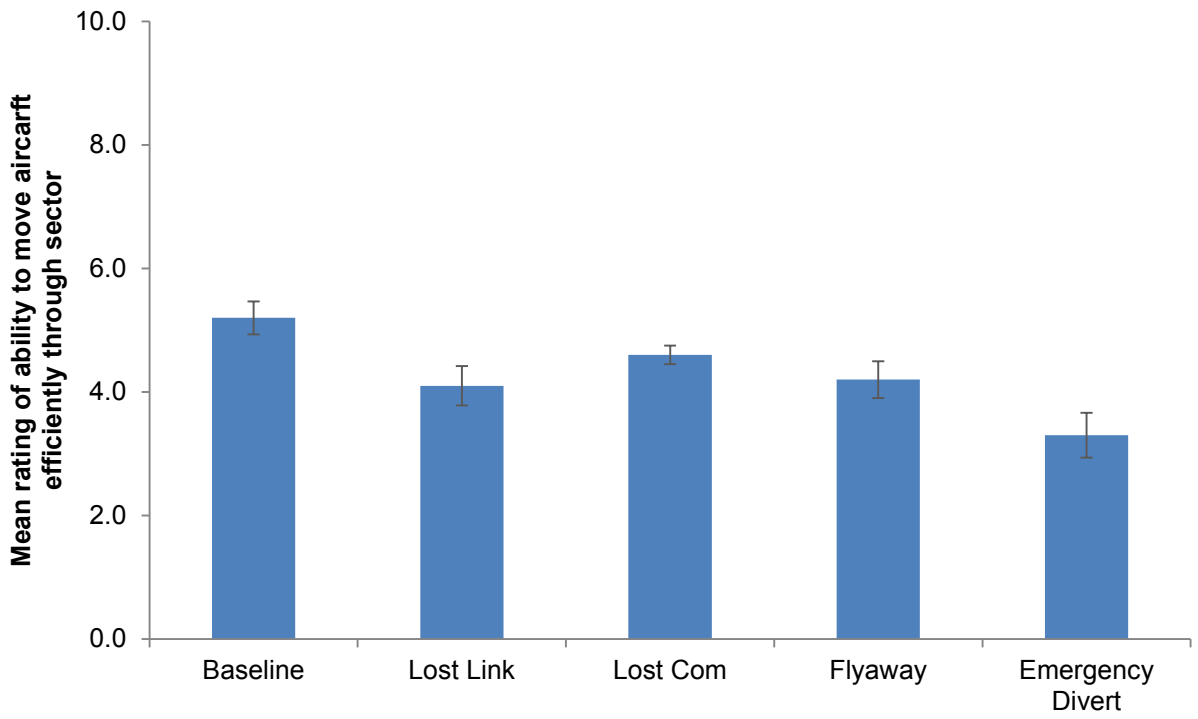

Figure 6-21 Configuration 3, Mean ATCS Rating of Ability to Move AC Efficiently (Mulford)

Analyses showed that contingency events had a significant effect on the controllers' subjective assessment of their ability to move aircraft efficiently through their sector (F (4, 40) = 7.05, $p < 0.05$). Tukey's post-hoc test showed that their self-assessed rating of this efficiency in the lost-link condition (M = 4.2, SE = 0.3) and emergency divert condition (M = 3.4, SE = 0.4) were significantly lower than the baseline condition (M = 5.2, SE = 0.3), indicating that controllers sensed that efficiency was degraded due to the contingency operations.

Table 6-2 and Table 6-3 summarize some relevant results from the post-scenario questionnaire data for both Mulford and Grove sectors, and the significant results are shown in bold. Comprehensive results can be found in the Appendix.

Table 6-2 Summary of Post-Scenario Questionnaire Data (Mulford)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Emergency Divert
NASA-TLX, Mental Demand	5.83	6.08	6.50	6.25	**7.33**
NASA-TLX, Physical Demand	3.00	3.33	3.75	3.75	4.00
NASA-TLX, Temporal Demand	4.67	5.25	5.58	5.92	**6.67**
NASA-TLX, Performance	7.64	6.82	6.36	6.82	**5.82**

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Emergency Divert
NASA-TLX, Effort	5.92	6.25	6.75	6.42	**7.50**
NASA-TLX, Frustration	3.83	3.83	4.50	4.58	5.17
Overall effectiveness of sector management and services provided	7.25	6.67	6.42	6.08	**5.67**
Overall Safety	8.08	6.92	7.08	**6.17**	**5.83**
Overall Efficiency	7.08	6.08	6.00	6.25	**5.25**
Ability to identify and resolve aircraft conflicts safely	5.09	4.45	4.82	4.55	**3.36**
Ability to move aircraft efficiently through the sector	5.18	**4.18**	4.55	4.27	**3.36**
Overall Workload	6.09	6.91	6.91	6.73	**7.64**
Workload due to controller-to-front line manager communications	1.50	**3.70**	**4.10**	**3.50**	**3.60**
SA for detecting aircraft conflicts	7.83	7.33	6.83	6.33	**6.25**
Overall difficulty of the scenario	5.75	6.75	6.50	6.17	**7.83**

Table 6-3 Summary of Post-Scenario Questionnaire Data (Grove)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Emergency Divert
NASA-TLX, Mental Demand	3.83	4.67	4.00	4.00	**6.83**
NASA-TLX, Physical Demand	2.67	2.50	2.33	2.25	4.00
NASA-TLX, Temporal Demand	3.08	3.50	3.50	3.08	**6.67**
NASA-TLX, Performance	8.08	7.33	8.00	7.58	7.00
NASA-TLX, Effort	4.33	5.33	4.25	4.33	**7.33**
NASA-TLX, Frustration	2.83	3.17	2.25	2.92	**5.33**
Overall Safety	8.08	7.92	8.00	7.75	**6.67**
Overall Efficiency	7.58	7.58	7.67	7.67	**5.67**
Ability to identify and resolve aircraft conflicts safely	5.27	5.09	5.09	5.18	**4.00**
Ability to move aircraft efficiently through the sector	4.91	4.73	5.00	5.09	**3.27**

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Emergency Divert
Overall Workload	4.42	5.08	5.08	4.50	**7.92**
Workload due to controller-to-pilot communications	4.75	4.00	3.83	3.83	**6.83**
Overall level of SA	8.00	**6.82**	7.55	7.36	7.36
Overall difficulty of the scenario	4.18	4.64	5.00	4.00	**7.45**

6.3.3 Efficiency Data

The controllers' subjective assessments of degraded efficiency were supported by analyses of the recorded aircraft track and status information. In addition, as this was the arrival configuration, the number of arrival delays was tallied, to provide an added measure to evaluate the effect of UAS contingency operations on system efficiency.

6.3.3.1 Flight Time

The aircraft track data was used to determine flight times and distances for the sector in each scenario. Notionally, if a contingency operation requires reroutes for other aircraft, the result would be longer flight times and distances flown in the sector. Such effects were indeed observed, and as an example, the results in Figure 6-22 show the total flight times that aircraft spent in the Grove sector.

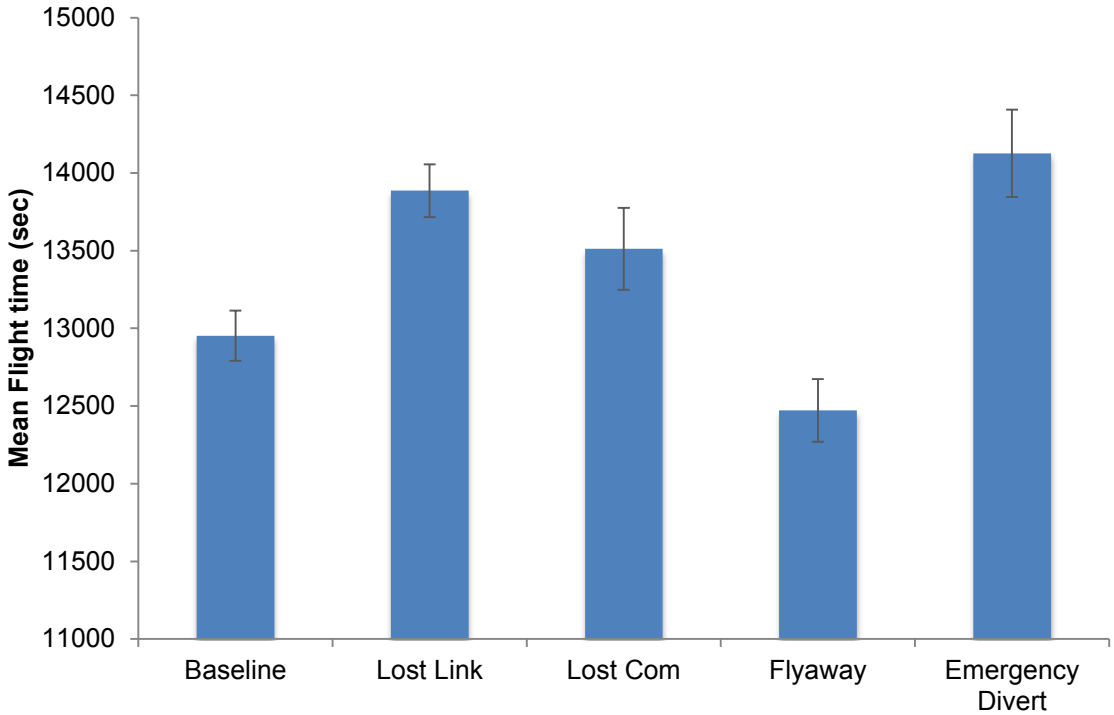

Figure 6-22 Configuration 3, Mean Flight Time (Grove)

Analyses showed that contingency operations had a significant effect on total flight time (F (4, 44) = 11.13, $p < 0.05$). Tukey's post-hoc test showed that the total flight time during the lost link on arrival condition (M = 13,886.2 sec, SE = 161.3) and the emergency divert condition (M = 14,126.6 sec, SE = 170.1) were significantly higher than the baseline condition (M = 12,952.4 sec, SE = 282.0), indicating that these two contingency events greatly affected the airspace efficiency by causing flights to spend longer durations of time in the sector. Results for flight distance are similar, and can be found in Appendix P.

6.3.3.2 Delay

In addition to flight time and distance, arrival delays were measured to evaluate efficiency. Examining the number of delays can provide insights into how controllers managed the particular contingency operation, and the corresponding effect on system efficiency. This effect is captured in Figure 6-23, which shows the average number of arrival delays that occurred in the Mulford sector.

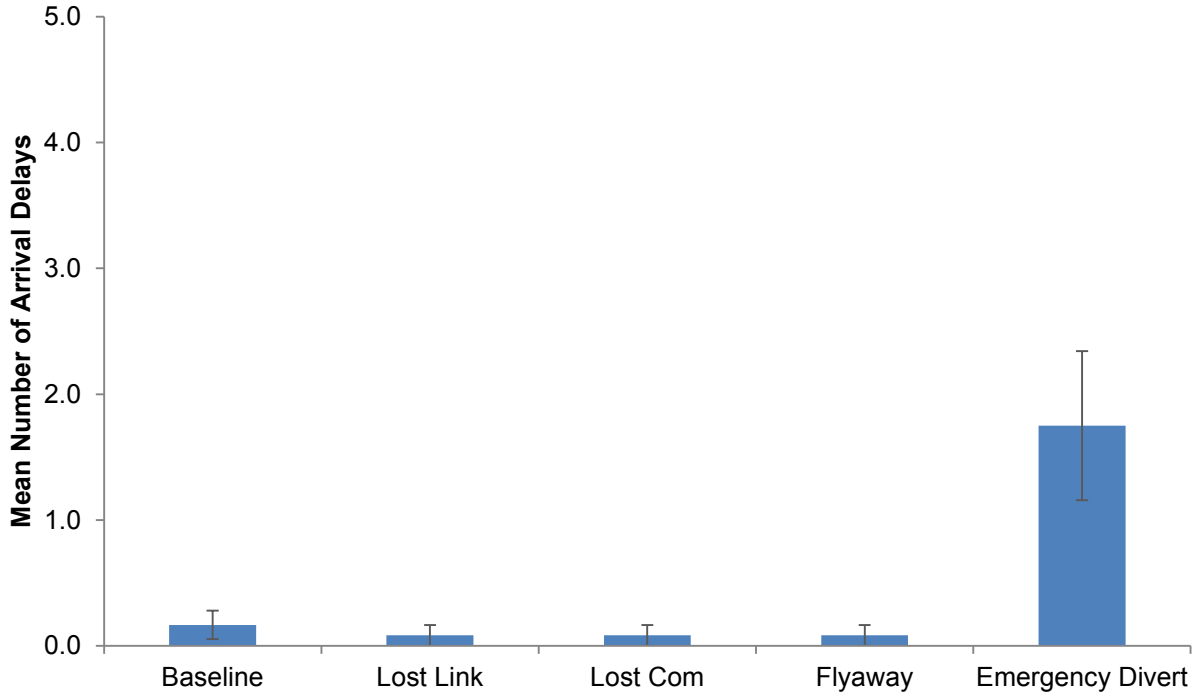

Figure 6-23 Configuration 3, Mean Number of Arrival Delays (Mulford)

Analyses showed that contingency operations had a significant effect on the number of arrival delays (F (4, 44) = 8.65, $p < 0.05$). Tukey's post-hoc test showed that the mean number of arrival delays that occurred during the emergency divert condition (M = 1.8, SE = 0.6) was significantly higher than the baseline condition (M = 0.2, SE = 0.1), indicating the reduced efficiency potentially caused by these contingency operations. As these events occur and disrupt the normal flow of traffic, controllers needed to enact commonly used tools to delay traffic in order to maintain safe operations. As such, the analyses indicate the lack of a significant effect on system safety, but a significant effect on system efficiency.

7 Discussion and Conclusions

This simulation was conducted in an effort to address the impact of UAS contingency events on NAS operations and air traffic controllers.

From the perspective of the controllers, contingency operations contributed to an overall increase in their experienced workload. This was reflected in increased amounts of communication between controllers and pilots, as well as controllers and the front line manager. This increased workload potentially led also to reduced levels of SA, reduced sense of effective sector management, increased difficulty in dealing with the scenario, and an overall subjective sense of reduced safety. These assessments were primarily a result of the perceived unpredictability of the UAS contingency operation, as one controller expressed, a result of "not knowing what this guy is going to do."

Such assessments may indicate that UAS contingency operations would contribute to reduced levels of system safety. However, this research uncovered no significant impacts of contingency operations on objective measures of system safety, providing a strong indication that controllers were able to maintain safety despite the adverse conditions that they encountered.

These findings support the ATC mandate of maintaining safety as the highest priority as directed in Paragraph 2-2a of FAA Order 7110.65V:

> *Give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment must be used in prioritizing all other provisions of this order based on the requirements of the situation at hand.*

The controllers, in full compliance with the mandate, were observed using common controller techniques to delay traffic in order to maintain safety. In most cases, the increased number of delays resulted in aircraft spending more time and flying longer distances within each sector, while the controllers worked to "get it [the sector] back to a manageable level," as expressed by one participant. These effects on efficiency were observed in all three configurations, which controllers recognized as, while not desirable, an acceptable consequence of prioritizing safety.

To support this conclusion, Figure 7-1 is provided as an example of the relationships between safety, efficiency, and workload by displaying a sequence of events from Configuration 2. For this configuration, the CI position's role was to provide general assistance to the radar controller. The responsibilities included: inter- and intra-facility coordination, release of departures, coordination of arrival information, flight strip management, and general sector workload management. As this position best represents the controller workload affected for this configuration, the WAK ratings for the CI are shown with respect to the scenario time scale (thirty-minute duration).

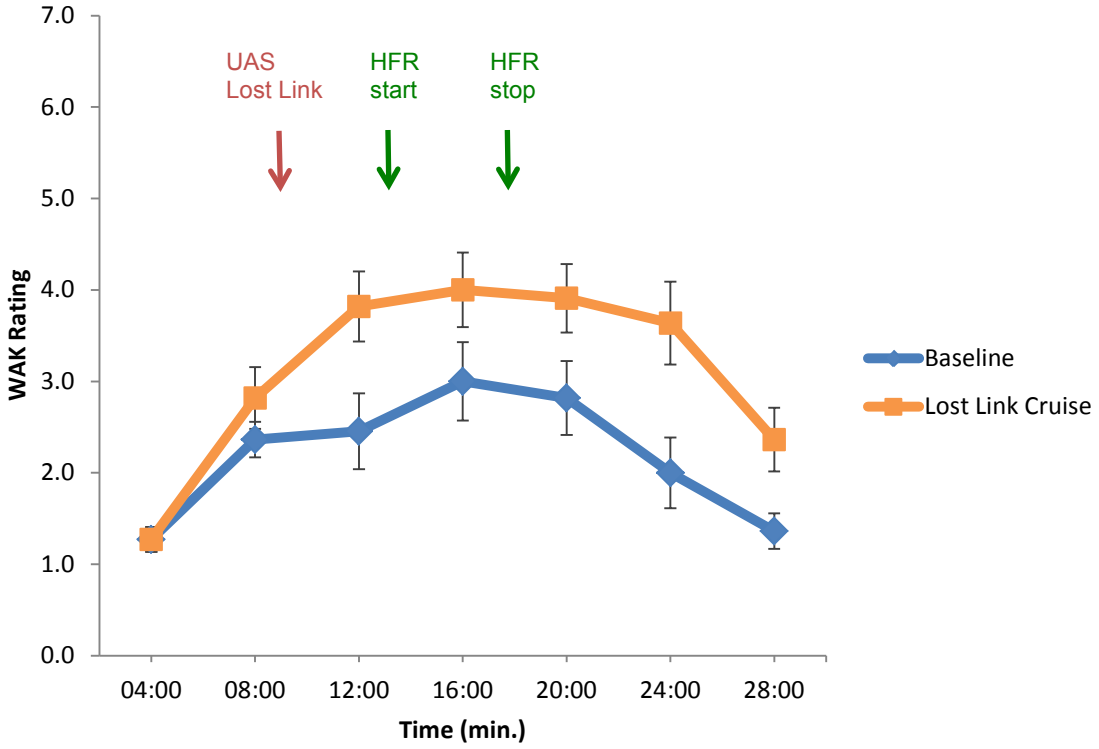

Figure 7-1 WAK Ratings for Duration of Scenario

As shown in Figure 7-1, a significant difference in workload occurs at the 12:00-minute mark (F (4, 40) = 5.11, $p < 0.05$). Tukey's post-hoc test showed that the WAK rating at the 12-minute mark for the lost link-cruise condition ($M = 3.8$, $SE = 0.4$) was significantly higher than that for the baseline condition ($M = 2.5$, $SE = 0.4$). The figure also illustrates when the controller in the lost link scenario instituted a HFR. Through such actions, controllers may be attempting to manage their workload by delaying traffic under their control, preserving their attentional and cognitive resources to focus on maintaining system safety. For the purposes of clarity, the non-significant results of the other scenario conditions are not shown in Figure 7-1.

By design, in depth analysis of "non-event" UAS operations was outside the scope of this research and therefore all UAS scenarios included a planned contingency. For the objectives of this study, the assumption was made that that there would be no operational difference between the baseline runs used (all of which include only manned aircraft), and a set of baseline runs which would include UAS that did not experience any abnormal operations. However, it is fully recognized that abnormal events do occur, and improved understanding and methods to mitigate the impact of UAS contingency operations is needed to achieve full acceptance for integration.

To support the baseline assumption of the study, analyses of the "non-event" periods of operations (i.e., from 0:00 to 08:00 minutes) were conducted. For example, Figure 7-1 also illustrates that there was no significant difference between how the controllers rated workload between the baseline and lost link scenarios during the "non-event" period. However, once the UAS experiences the lost-link event in the lost link scenario, a significant increase in the

workload occurs as compared to baseline, as shown by the result at the 12:00-minute mark. Furthermore, there were no significant effects seen in the safety and efficiency measures analyzed for these portions of the data. The results in relation to this particular discussion seem to indicate that "non-event" UAS operations could be acceptable for NAS integration. While the sampling of these "non-event" periods of UAS operations is admittedly of smaller time scales than the time periods of UAS contingency operations, they suggest that "non-event" UAS operations in the NAS would not have significant impacts on system safety, efficiency, or controller workload. Results of the analyses can be found in Appendix Q.

Lastly, in an effort to uncover the information controllers needed to handle and mitigate the impact of these contingency events, two questions were posed during the post-experiment questionnaire:

- What immediate information did you (ATCS) need to handle this UAS emergency/event?
- What follow-up information did you (ATCS) need to handle this UAS emergency/event?

Controllers were asked to choose among seven categories of responses to these questions, as follows:

- Type of Failure
    - The exact nature of the UAS system failure. For example, did the pilot still have control? Would ATC be able to communicate via radio frequency or did they have to wait for telephone/land line communication channels to be opened?
- UAS Capabilities
    - UAS performance capabilities, both during routine operations and contingency events. In addition, what recovery capabilities were possible with the UAS during a contingency event (i.e., can the UAS regain link and if so would it be just communication and/or control)?
- Lost Link (LL) Procedures
    - Knowledge and understanding of what ATC should expect from the UAS during a lost-link event.
- UAS Communication (Comm) Issues
    - Understanding when a land line connection would be established, whether all communications would have to be relayed through the FLM, and whether they could have the ability to directly communicate with the UAS pilot.
- Pilot Intentions
    - Understanding what the pilot wants to do. This is needed so ATC can comply with the pilot's intentions, as well as plan their traffic to accommodate those intentions.
- ATC Issues
    - ATC coordination requirements with adjacent airspace or facilities.
- Verification Issues
    - Verifying clearances relayed through FLM or other third party sources (i.e., were they received, received properly and going to be executed properly).

Figure 7-2 shows the responses regarding the immediate information that was needed, and Figure 7-3 shows the responses regarding the follow-up information that was needed by the controllers to handle the UAS event.

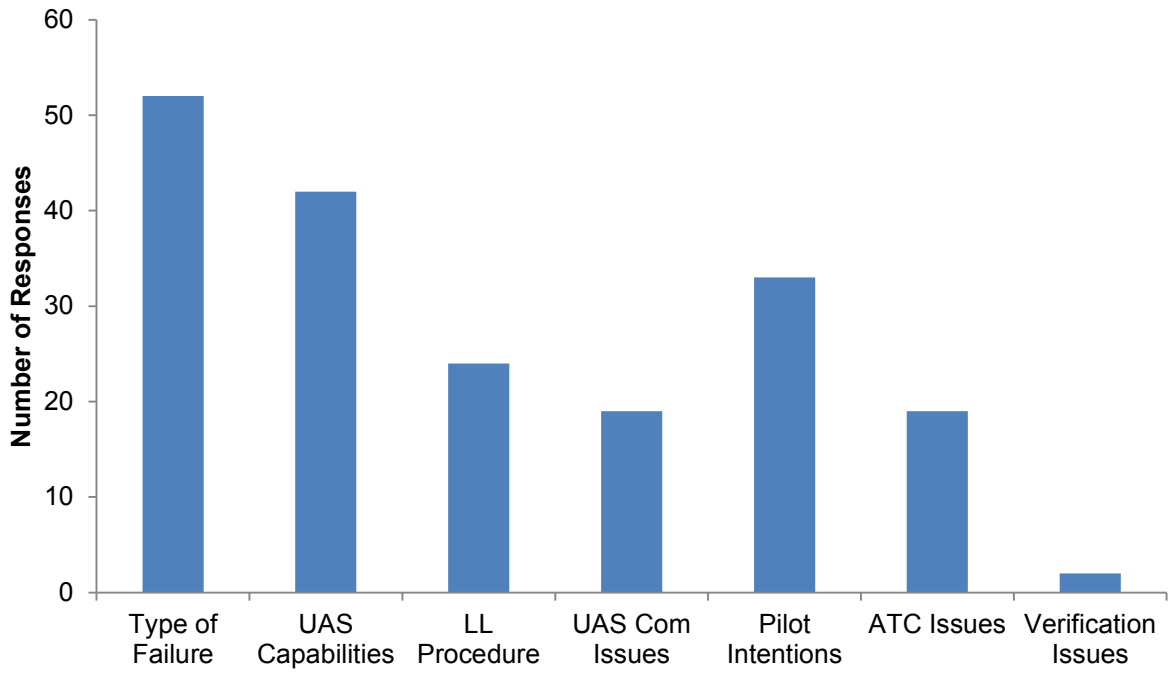

Figure 7-2 Immediate Information Needed to Handle UAS Event

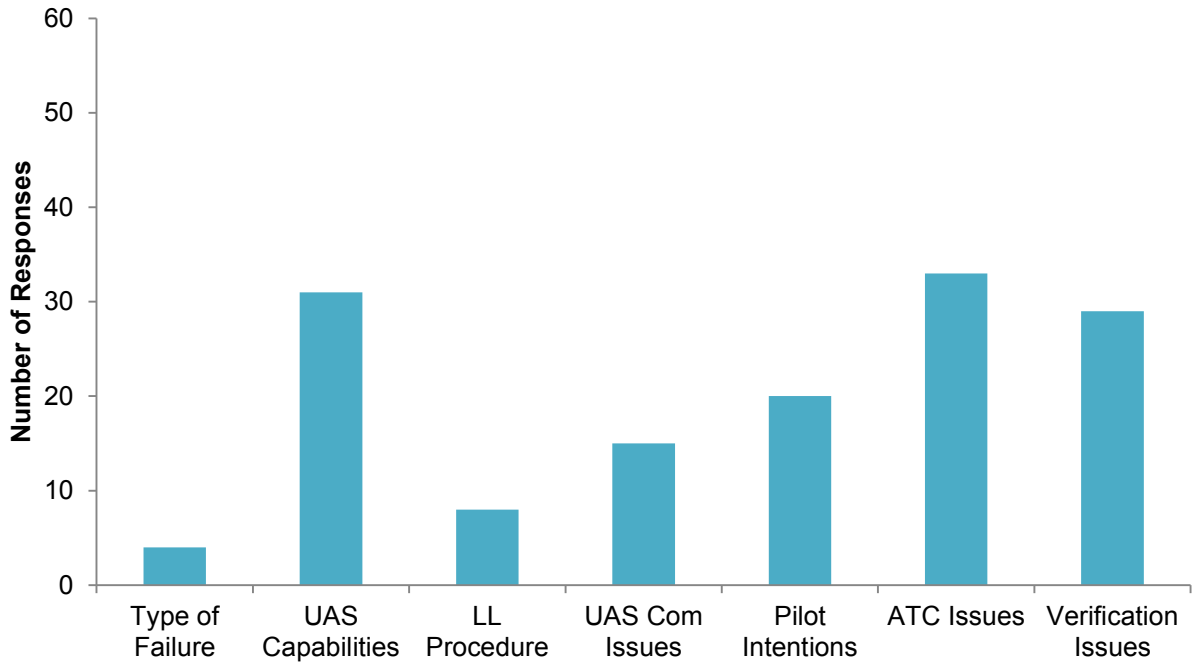

Figure 7-3 Follow-up Information Needed to Handle UAS Event

The results show that most controllers' immediate information need was the type of failure that occurred. This was most notably demonstrated in the ambiguity between the lost link and lost communication scenarios, where controllers needed to disambiguate and establish the failure type of the UAS. The controllers also indicated a need to know the capabilities of the UAS, as well as the intentions of the pilot. This was particularly relevant in the lost communication scenario, in which the pilot retained control link of the UAS, but the controller could not communicate directly with the pilot. Once the controllers had received the initial information and established the failure type, their follow-up information needs included UAS capabilities, ATC issues, and verification issues. The controllers needed information about the UAS, information from adjacent sectors and facilities, and when direct communication with the pilot was not available, verification information was needed.

All of these findings, along with controller feedback provided during the out-briefs, support the conclusions of this study. Despite the adverse conditions that controllers encountered in the various scenarios, they demonstrated the capability to safely handle the given contingency operations. It is the opinion of the authors that this is indeed a testament to the resilience and adaptability of controllers and their ability to handle unexpected circumstances in maintaining the priority of safety above all else. These conclusions afford many considerations and recommendations for furthering the progress of UAS integration into the NAS, described in the following section.

8 Recommendations

Given the results provided, analyses of the post-experiment debrief data yielded the most common concerns of UAS contingency operations, as expressed by the controllers. These serve to provide recommendations for future work to further address these topics in aiding the successful integration of UAS into the NAS.

8.1 UAS Predictability

One of the most common discussion points during the study involved UAS predictability, during both "non-event" (normal) and emergency operations. It is important for controllers to have the ability to anticipate and/or predict aircraft performance and compliance with instructions and procedures. One controller referred to this as "developing a trust factor" with the UAS. Specific procedures during lost-link conditions were a prime concern, and controllers reacted favorably when the UAS followed the briefed procedure(s) and one participant stated with regards to the UAS lost link procedure, that he "felt more comfortable when the UAS performed as briefed," and when asked about the UAS following the briefed lost link procedure, he further stated that "it was more predictable than a manned aircraft with lost communications."

Documented responses indicated that controller familiarity with specific UAS operational flight characteristics during routine operations tended to improve as the study progressed for each participant group, with a corresponding increase in the level of comfort and confidence with regards to UAS predictability. This was substantiated by at least one participant who stated that he was "more cautious at first, but grew more comfortable," and one participant who added that as he "got used to the UAS, it became easier."

Future research should further substantiate the importance of the predictability of UAS operations on the safety, efficiency, and capacity of the NAS. Research should explore implementation of tools and/or methods to establish the predictability of UAS operations, especially during off-nominal events. One example would be further research on the potential applicability of ACE-IDS displays for supporting UAS operations.

8.2 Lost Link Procedure

ATC participants generally disagreed with the use of a single lost-link procedure per facility that was universally applied for all airspace configurations. As was demonstrated during the study, intricate and complex airspace design requirements presented a challenge to the single lost link concept. The controllers suggested that there was a need for multiple lost link procedures, dependent upon the current airspace configuration(s), that a single lost-link procedure would be "not good", and that the procedure should be "dependent upon runway configuration."

Some participants suggested a more "dynamic" lost link procedure, especially during the arrival phase that would take into account the current position of the UAS, with respect to the final approach course and landing runway. Some participants suggested that during the arrival phase, a transition to a lost-link procedure that more closely mimicked the standard manned aircraft no-radio arrival procedure would have provided a more workable solution, with minimal impact upon the overall operations within the sector. Several participants remarked that "it would be

better for the UAS to go missed approach," and one participant added that if the lost link occurred on approach, the UAS should "continue and land."

Future research should explore these types of standard and/or dynamic lost link procedures (e.g., missed approaches and/or controller initiated go-arounds), as well as the impact of lost link procedures for the operation of multiple UAS. Such research could yield insights into the types and quantity of procedures that may minimally disrupt operations, but also yield insights into what types and quantity would lead to higher cognitive load of the controller.

8.3 Communication

As part of the study design, an emergency communications line between the ATC facility and the GCS was established, that included a relay through the area FLM. The ability to speak to the pilot after a loss of radio communication through the vehicle is a benefit of UAS operations. Although controllers agreed that having a fail-safe emergency communications link was beneficial, the participants would have preferred a more direct communication line that terminated directly at the sector(s), thus removing the "third-party" relay. Participants commented that they "would feel more comfortable with a direct line and eliminating the third person relay," and some felt that the communication system, as simulated, was "problematic." With current technologies already present in facilities, telephone lines could be routed direct to air traffic controller positions (whether radar controller, assistant controller or coordinator position).

Future work should explore the use of direct communication lines and evaluate the benefits and drawbacks of such a communication system. The communications results from this study should directly inform and be incorporated into the related UAS communications research to be conducted this fiscal year (FY 14 and FY 15 under AllL.UAS.5.2).

8.4 Lost Link Beacon Code

A consistently reoccurring topic of discussion (and a topic reaffirmed by our data) was the need for ATC to have immediate and accurate information on aircraft status and pilot intentions, for both manned and unmanned operations. This was especially relevant during UAS Lost Link situations and the need for a discrete beacon code to signify such.

As this study emulated current operations, UAS loss of communications and/or control links triggered the same discreet transponder code of 7600, which is universally accepted within ATC as the code for loss of radio communications. Sharing the beacon code for lost link with loss of radio communication resulted in some confusion and delay in action, as controllers attempted to ascertain the exact nature of the failure, and whether or not aircraft control was still available.

A majority of ATC participants commented that the separate lost link code concept would be "helpful" and "preferred." It is recommended that a discrete beacon code to signify lost link (loss of control link) be mandated and adopted by the global aviation community. Such a code was expressed as a positive future capability.

Future research should evaluate the utility of the specific lost link code, and measure the benefits gained by controllers immediately knowing the failure type.

8.5 ATC Operational Priority

Notwithstanding emergencies and other special flights, "First Come, First Served" has always been a longstanding concept for controllers, with regards to prioritizing operations within the NAS. Until the advent of unmanned aircraft, the "First Come, First Served" concept carried the assumption that all aircraft operations/missions were essentially equal and that no one mission carried any more importance than others. Part of this rationale was based on the assumption that all operations actively involved people, acting either solely as flight crew or flight crew with passengers. Although at the tactical level, strict adherence to the "First Come, First Served" concept would occasionally require some modification due to operational practicality, the overriding principle of "mission equality" generally remained intact.

Documented responses during the study showed that controllers often questioned how the unmanned nature of UAS operations may or may not impact the application of the "First Come, First Served" concept, and how the mission priority of UAS operations compared to manned flights. One controller stated that the UAS "would be last, since there is no one on board."

Operational priority with regards to UAS emergencies was also a topic of discussion. Due to the unmanned nature of the aircraft, to what extent do the existing ATC emergency handling procedures differ, if at all? For example, when handling a UAS experiencing a progressively deteriorating mechanical condition, how do controllers balance efforts to save the UAS airframe, against the potential risk and physical harm to manned aircraft personnel/property on the ground beneath the flight path of the UAS? One controller remarked that a UAS emergency was a "priority call," and that he would have to evaluate the "likelihood of the UAS making the airport, versus remaining over water for safety, and to avoid densely populated areas." Another participant remarked that he would "treat the aircraft differently, if he knew there were people on board," and "would make more of an effort to ensure a safe landing" if people were on board.

Due to the unique operational characteristics of UAS, ATC procedures during emergency operations may require further examination and modification to address the differences between manned and unmanned aircraft.

8.6 Training and Familiarization

Lastly, all controllers expressed the need for comprehensive and in-depth training, covering all aspects of UAS operations, with an emphasis on ATC responsibilities and procedures concerning UAS handling for all classes of airspace. Some participants responded that their comfort level and confidence increased as they gained more experience with UAS operations, including familiarity with aircraft performance capabilities and specific UAS procedures. Documented responses and discussions revealed that although controllers were pre-briefed on general UAS procedures, there were many unanswered questions, as the current FAA JO 7110.65 does not contain guidance and/or specific handling requirements for UAS operations. These include ATC responsibilities during UAS emergencies, UAS vs. manned aircraft priority, UAS traffic advisories, UAS lost-link procedures, separation standards, and chase plane operations.

As evidenced by controller comments and the improvements observed in their handing of UAS as the simulation progressed, it is recommended that all controllers who handle UAS operations

receive formal training with UAS operations that includes special emphasis on the handling of contingency operations.

9 Acronyms

3M	Mulford Sector
3G	Grove Sector
4R	Richmond Sector
4U	Sutro Sector
A/G	Air/Ground
AC	Aircraft
ACE	FAA Central Region
AFS-80	FAA Flight Standards Service (AFS), UAS Integration Office
AFS-83	FAA AFS UAS Integration Office-Safety and Data Management
AFS-88	FAA AFS UAS Integration Office-R&D Section
ANG-C2	FAA NextGen Research and Development Integration Division
ANG-C3	FAA NextGen Engineering Development Services Division
ANG-C35	NextGen Engineering Development Services Division-UAS Engineering Branch
ANG-E142	FAA NextGen Integration and Evaluation Capability (NIEC) Lab
ANG-E18	FAA NextGen Tower/TRACON Modeling & Simulation Branch
ANG-E25	FAA NextGen Human Factors Field Branch
ANG-E272	FAA NextGen Aviation Research Division SW & Systems Branch
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATCT	Airport Traffic Control Tower
ATWIT	Air Traffic Workload Input Technique
AVS	FAA Office of Aviation Safety
BL	Baseline
C2	Command and Control
CA	California
CFR	Code of Federal Regulations
CI	(ATC) Coordinator position
CO	Configuration
COA	Certificate of Authorization
COMM	Communications
Comm	Communications
Config.	Configuration
Co-PI	Co-Principal Investigator
DC	District of Columbia
DESIREE	Distributed Environment for Simulation, Rapid Engineering & Experimentation
DOT	Department of Transportation
DSR	Display System Replacement
DV	Emergency Divert
e.g.	Exempli Gratia, For example
EDW	Edwards Air Force Base, CA
EF	Engine Failure
ERAM	En Route Automation Modernization

et al.	Et alia, "And others"
etc.	Et Cetera, And so forth
ETVS	Enhanced Terminal Voice Switch
F	F-Factor
FA	Fly-away
FAA	Federal Aviation Administration
FLM	Front Line Manager
FPS	Flight Progress Strip
FT	Flight Termination
FTP	Flight Termination Point
FY	Fiscal Year
G/G	Ground-to-Ground
GCS	Ground Control Station
GDIT	General Dynamics Information Technology
GPS	Global Positioning System
HFR	Hold For Release
HITL	Human-In-The-Loop
HO	Handoff
HSD	Honestly Significant Difference
HWD	Hayward Executive Airport, CA
i.e.	Id Est, That is
ID	Identification
IFR	Instrument Flight Rules
IVSR	Interim Voice Switch Replacement Program
JO	Joint Order
JPVD	Java Plan View Display
K	One thousand
L	Left
LC	Lost Communications
LCCCS	Laboratory Combined Control and Communications System
LCD	Liquid Crystal Display
LCT	Lost Communications (Lost transmit only)
LL	Lost Link
LLC	Limited Liability Corporation OR Lost Link-Cruise
LLD	Lost Link-Departure
LLM	Lost Link-Multiple
LLP	Lost-link Loiter Point
LOA	Letter of Agreement
LOS	Loss of Separation
MA	Massachusetts
MHz	MegaHertz
MIT LL	Massachusetts Institute of Technology/Lincoln Laboratory
Mt.	Mount
MVA	Minimum Vectoring Altitude
N/A	Not Applicable
NAS	National Airspace System

NASA	National Aeronautics and Space Administration
NCT	Northern California TRACON
NextGen	Next Generation Air Transportation System
NIEC	NextGen Integration and Evaluation Capability
NJ	New Jersey
NM	Nautical Mile (1.15 Statute Miles = 1.852 km)
OAK	Oakland Airport - CA
Ph.D.	Doctor of Philosophy
PIC	Pilot-In-Command
PII	Personally Identifiable Information
POC	Point of Contact
PTT	Push-to-Talk
R&D	Research and Development
RAPCON	Radar Approach Control
RCE	Radio Control Equipment
RDHFL	Research Development Human Factors Laboratory
RDVS	Rapid Deployment Voice Switch
RF	Radio Frequency
RTB	Return to Base
Rx	Receiver
SA	Situation Awareness
SE	Significant Error
SFO	San Francisco International Airport, CA
SJC	San Jose Airport - CA
SME	Subject Matter Expert
SOP	Standard Operating Practice
STARS	Standard Terminal Automation Replacement System
STVS	Small Tower Voice Switch
TASC	The Analytic Sciences Corporation
TCRG	Technical Community Representative Group
TGF	Target Generation Facility
TLX	Task Load Index
TN	Technical Note
TRACON	Terminal Radar Approach Control
U.S.	United States
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System(s)
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
vs.	Versus
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center
ZOA	Oakland ARTCC

10 References

Abrahamsen, T., & Fulmer, D. (2013). Unmanned Aircraft Systems (UAS) operational issues identification and mitigation. McLean, Virginia: The MITRE Corporation.

Buckley, E. P., DeBaryshe, B. D., Hitchner, N., & Kohn, P. (1983). Methods and measurements in real-time air traffic control system simulation (DOT/FAA/CT-83/26). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

FAA Order 7110.65V, Air Traffic Control. (2014). Federal Aviation Administration. Washington, DC: US Government Printing Office.

Federal Aviation Administration. (2012c). Right of way rules (CFR 14 Ch. 1F, Part 91B §91.113). Washington, DC: FAA.

Federal Aviation Administration. (2013). Crewmember duties (CFR 14 Ch.1G Part 121T §121.542). Washington, DC: FAA.

Fern, L., Kenny, C., Shively, R.J., & Johnson, W. (2012). 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*, Boston, MA, October 22-26.

Fern, L., Rorie, R., & Shively, R. (2014). UAS contingency management: The effect of different procedures on ATC in civil airspace operations. Moffett Field, CA.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Human mental workload, 1(3), 139-183.

Hu, Q., Jella, C., Letourneau, J., Williamson, G., Jones, S., Jaranson, K., Sward, R. (2010). Intelligent UAS situation awareness and information delivery. Bedford, MA: The MITRE Corporation.

Sollenberger, R. L., Stein, E. S., & Gromelski, S. (1997). The development and evaluation of a behaviorally based rating form for assessing air traffic controller performance (DOT/FAA/CT-TN96/16). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Stein, E. S. (1985). Controller workload: An examination of workload probe (DOT/FAA/CT-TN 84/24). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Stein, E. S. (1991). Air traffic Controller Memory - A Field Survey (DOT/FAA/CT-TN90/60). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Stein, E. S., & Buckley, E. P. (1992). Human factors at the FAA Technical Center: Bibliography 1958-1994 (DOT/FAA/CT-TN94/50). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Vardaman, J. J., & Stein, E. S. (1998). The development and evaluation of a behaviorally based rating form for the assessment of En Route air traffic controller performance (DOT/FAA/CT-TN98/5). Atlantic City International Airport: Federal Aviation Administration William J. Hughes Technical Center.

This page intentionally left blank.

Appendix A: Informed Consent Statement

I, _____, understand that this study, entitled "Operational Assessment: UAS Contingency Operations" is sponsored by the Federal Aviation Administration and is being directed by Bina Pastakia.

Nature and Purpose:

I have been recruited to volunteer as a participant in this project. The purpose of the study is to conduct a high-fidelity human-in-the-loop simulation to determine how Unmanned Aircraft Systems (UAS) integration may affect air traffic operations in Class C airspace. The results of the study will be used to identify future research and to inform air traffic control standards and procedures for integrating UAS into the National Airspace System.

Experimental Procedures:

The study will require a total of 24 Certified Professional Controllers recruited from Northern California TRACON (NCT) to act as participants. The controllers will participate in small groups of 2 or 3 controllers in each session for a total of 10 sessions in the entire study. Each group of controllers will be released from their facility for 5 days to participate in the study. The first day is scheduled for travel to the FAA William J. Hughes Technical Center and the last day is scheduled for return travel. In each of the remaining 3 days, the controllers will report to the NextGen Integration and Evaluation Capability Laboratory to participate in our ATC simulation.

Each simulation day will last from 8:00 AM to 4:00 PM, with a one-hour scheduled lunch break and several break periods during the day. In the morning of the first day, the research team will present a study briefing and the participants will complete a Biographical Questionnaire. After the briefing, the controllers will report to the laboratory to work the traffic scenarios prepared for the study. After each scenario, the participants will complete a Post-Scenario Questionnaire. On the second and third day of simulation, the controllers will continue to work the simulation scenarios. In the afternoon of the third day, the research team will conduct a group discussion and the participants will complete a Post-Experiment Questionnaire.

Each of the simulation scenarios will last 30 minutes and consist of realistic traffic from NCT airspace. Some scenarios will consist of UAS contingency operations and other scenarios will not have UAS traffic. During each scenario, SMEs from the research team will observe the controllers and complete an Observer Rating Form. In addition to the questionnaires, other ATC data will be collected during the simulation including system safety, capacity, and efficiency measures as well as controller communications and workload. The entire simulation will be audio-video recorded.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques. I understand that I will not be exposed to any foreseeable risks beyond what I usually experience in my every day job.

Anonymity and Confidentiality:

My participation in this study is strictly confidential. All information that I provide will be anonymous to the experimenters. I understand that a participant code will be attached to my data for research purposes. My name and identity will not be released in any reports. All data collected in the study will be used for scientific purposes only and must be kept confidential by

law. Laboratory personnel will not disclose or release any Personally Identifiable Information (PII) to any FAA personnel or elsewhere, or publish it in any report, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.18 "Protecting Personally Identifiable Information (PII)."

Benefits:

I understand that I will be able to provide the researchers with valuable feedback and insight into the effects of UAS integration in Class C airspace. My data will help the FAA to establish the feasibility of these procedures within such an environment. I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight regarding UAS integration in the NAS. My data will help the FAA to identify the human factors issues with UAS integration and help inform FAA standards and procedures for UAS integration.

Participant Responsibilities:

I am aware that to participate in this study I must be a current Certified Professional Controller at NCT. I will control traffic and answer any questions asked during the study to the best of my ability. I will not discuss the content of the experiment with other potential participants until the study is completed.

Participant Assurances:

I understand that my participation in this study is completely voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe it is in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

Bina Pastakia has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Bina Pastakia or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Bina Pastakia at (609) 485-6822.

Compensation and Injury:

I agree to immediately report any injury or suspected adverse effect to Bina Pastakia at (609) 485-6822.

Signature Lines:

I have read this informed consent statement. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:_____ Date: _____

Investigator: _____ Date: _____

Witness: _____ Date: _____

Appendix B: Biographical Questionnaire

This questionnaire is designed to obtain information about your background and experience as an Air Traffic Control Specialist. Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

1. What is your **gender**?	○ Male	○ Female

2. What is your **age**?	_____ years
3. How long have you worked as an **ATCS (include FAA developmental, CPC, and military experience)**?	_____ years _____ months
4. How long have you worked as a **CPC for the FAA** (include Oceanic, En Route, TRACON, Tower)?	_____ years _____ months
5. How long have you **actively controlled traffic** in a TRACON facility?	_____ years _____ months
6. How many of the **past 12 months** have you actively controlled traffic in a TRACON facility?	_____ months

7. Rate your current **skill as a CPC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled
8. Rate your current **level of stress**.	Not Stressed	①②③④⑤⑥⑦⑧⑨⑩	Extremely Stressed
9. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

10. Do you have previous ATC **experience with UAS** at your facility?	○ Yes	○ No

10a. On average, how many **UAS operations** do you handle per month?	_____ per month

10b. In your work experience, how did **UAS operations affect the ATC services** in your sector?	Unfavorable Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Favorable Effect

Comments:

_____

_____

_____

_____

_____

_____

_____

_____

10c. Please list the **types of UAS** that you have worked.	

Appendix C: Post-Scenario Questionnaire

Please answer the following questions based upon your experience in the scenario just completed. The Task Load Index rating scales represent a standard technique to make inferences about user workload in any task. For our research purposes, the term "task" refers to controlling traffic in the simulation.

Task Load Index

1. **Mental Demand** – How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
2. **Physical Demand** – How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
3. **Temporal Demand** – How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
4. **Performance** – How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)?	Very Poor	①②③④⑤⑥⑦⑧⑨⑩	Very Good
5. **Effort** – How hard did you have to work (mentally and physically) to accomplish your level of performance?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High
6. **Frustration** – How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Performance

7. Rate the **overall effectiveness of sector management and services provided** to aircraft during the scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

8. Rate the **overall safety** of operations during the scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

9. Rate the **overall efficiency** of operations during the scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

10. What effect did the scenario traffic and events have on your **ability to identify and resolve aircraft conflicts safely**?	Negative Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Positive Effect

Comments:

_____

_____

_____

11. What effect did the scenario traffic and events have on your **ability to move aircraft efficiently through the sector**?	Negative Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Positive Effect

Comments:

_____

_____

_____

12. What effect did **UAS operations have on sector management and services provided** to aircraft? *If there were no UAS in the scenario, please respond* ○ N/A	Negative Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Positive Effect

Comments:

_____

_____

_____

Workload

13. Rate your **overall workload** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

14. Rate your **workload due to controller-to-pilot communications** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

15. Rate your **workload due to controller-to-front line manager communications** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

16. What effect did **UAS operations have on your overall workload**? *If there were no UAS in the scenario, please respond* ○ N/A	Negative Effect	①②③④ ⑤ ⑥⑦⑧⑨ / None	Positive Effect

Comments:

_____

_____

_____

Situation Awareness

17. Rate your **overall level of situation awareness** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

18. Rate your **situation awareness for detecting aircraft conflicts** during this scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

19. What effect did **UAS operations have on your overall situation awareness**? *If there were no UAS in the scenario, please respond* ○ N/A	Unfavorable Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Favorable Effect

Comments:

_____

_____

_____

Simulation Pilots and Scenario Difficulty

20. Rate the **overall performance of the simulation pilots** in terms of their responding to control instructions, phraseology, and providing readbacks.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

21. Rate the **overall difficulty** of the scenario.	Extremely Low	①②③④⑤⑥⑦⑧⑨⑩	Extremely High

Comments:

_____

_____

_____

Sector Management, Aircraft Effects, and Workload – Questions Apply to UAS Scenarios Only

22. How did the UAS event affect **overall sector management**?

Check All Effects that Apply	If Checked, Please Rate the Effect Severity		
○ Loss of Aircraft Separation	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Airborne Holding	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Stopped Departures	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Cancelled Approach Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Missed Approach	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Re-Sequenced Aircraft	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Amended Altitude or Other Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Repeated Transmissions	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Inter-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Intra-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Other, please comment			

Comments:

_____

_____

23. How did the UAS event affect **other aircraft**?

Check All Effects that Apply	If Checked, Please Rate the Effect Severity		
○ Loss of Aircraft Separation	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Airborne Holding	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Stopped Departures	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Cancelled Approach Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Missed Approach	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Re-Sequenced Aircraft	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Amended Altitude or Other Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Repeated Transmissions	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Inter-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Intra-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Other, please comment			

Comments:

_____

_____

24. How did the UAS event affect **your workload**?

Check All Effects that Apply	If Checked, Please Rate the Effect Severity		
○ Loss of Aircraft Separation	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Airborne Holding	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Stopped Departures	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Cancelled Approach Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Missed Approach	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Re-Sequenced Aircraft	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Amended Altitude or Other Clearance	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Repeated Transmissions	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Inter-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Increased Intra-Facility Coordination	No Effect	①②③④⑤⑥⑦⑧⑨⑩	Significant Effect
○ Other, please comment			

Comments:

_____

_____

25. What immediate information did you (ATCS) need to handle this UAS emergency/event?

_____

_____

_____

_____

_____

26. What follow-up information did you (ATCS) need to handle this UAS emergency/event?

_____

_____

_____

_____

_____

27. Do you have any additional comments or clarifications about your experience during this scenario?

_____

_____

_____

_____

_____

_____

_____

_____

This page intentionally left blank.

Appendix D: Post-Experiment Questionnaire

Please answer the following questions based upon your overall experience in the experiment you just completed.

Simulation Realism and Research Equipment

1. Rate the **overall realism of the simulation experience** compared to actual ATC operations.	Extremely Unrealistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic

Comments:

_____

_____

_____

2. Rate the **realism of the simulation hardware** compared to actual equipment.	Extremely Unrealistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic

Comments:

_____

_____

_____

3. Rate the **realism of the simulation software** compared to actual functionality.	Extremely Unrealistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic

Comments:

_____

_____

_____

Overall Effect of UAS Operations

4. In your opinion, what effect would **UAS operations have on Class C airspace**?	Unfavorable Effect	①②③④ ⑤ ⑥⑦⑧⑨ | None	Favorable Effect

Comments:

_____

_____

_____

5. What are the major challenges with integrating UAS operations in Class C airspace? (check all that apply)

○ ATC Procedures for UAS Contingency Events (Incidents & Accidents)	○ Inability of UAS to Use Standard Instrument Departure or Instrument Approach Procedures
○ ATC Service Requirements for UAS	○ Inability of UAS to Accept Visual Clearances
○ ATC IFR & VFR Separation Standards for UAS	○ Inability of UAS to See Other Traffic
○ ATC Wake Turbulence Standards for UAS	○ Lack of UAS See & Avoid Capability
○ ATC Training	○ Lack of UAS Ground Navigational Database
○ UAS Pilot Certification	○ Reliability of UAS Control & Communication Links
○ UAS Aircraft Certification	○ ATC-to-UAS Pilot Land line Communications
○ UAS Flight Performance Characteristics	○ Other, please comment

Comments:

_____

_____

_____

_____

_____

_____

_____

6. What additional tools, requirements, or procedures are needed to accommodate UAS operations in Class C airspace? (check all that apply)

○ ATC Procedures for UAS Contingency Events (Incidents & Accidents)	○ Inability of UAS to Use Standard Instrument Departure or Instrument Approach Procedures
○ ATC Service Requirements for UAS	○ Inability of UAS to Accept Visual Clearances
○ ATC IFR & VFR Separation Standards for UAS	○ Inability of UAS to See Other Traffic
○ ATC Wake Turbulence Standards for UAS	○ Lack of UAS See & Avoid Capability
○ ATC Training	○ Lack of UAS Ground Navigational Database
○ UAS Pilot Certification	○ Reliability of UAS Control & Communication Links
○ UAS Aircraft Certification	○ ATC-to-UAS Pilot Land line Communications
○ UAS Flight Performance Characteristics	○ Other, please comment

Comments:

_____

_____

_____

_____

_____

_____

_____

7. Do you have any additional comments regarding the experiment?

_____

_____

_____

_____

_____

_____

_____

This page intentionally left blank.

Appendix E: Observer Rating Form

Instructions

This rating form is intended to be used by Front Line Managers (FLMs) or Subject Matter Experts (SMEs) to evaluate the effects of Unmanned Aircraft Systems (UAS) on controllers working in simulation environments. FLMs or SMEs will observe controllers working traffic scenarios with UAS involving contingency operations and also scenarios without UAS as a baseline condition for comparison. The observers will rate the performance of controllers in several different performance dimensions using the scale below as a general purpose guide. Use the entire scale range as much as possible. Take extensive notes on what you see. Do not depend on your memory. Write down your observations. Space is provided after each scale for comments. You may make preliminary ratings during the course of the scenario. However, wait until the scenario is finished before making your final ratings and remain flexible until the end when you have had an opportunity to see all the available behavior. At all times please focus on what you actually see and hear. This includes what the controller does and what you might reasonably infer from the actions of the pilots. If you do not observe relevant behavior or the results of that behavior, then you may leave a specific rating blank. Also, please write down any comments that may help improve this evaluation form. Do not write your name on the form itself. You will not be identified by name. An observer code known only to yourself and the researchers conducting this study will be assigned to you. The observations you make do not need to be restricted to the performance areas covered in this form and may include other areas that you think are important.

Assumptions

ATC is a complex activity that contains both observable and unobservable behavior. There are so many complex behaviors involved that no observational rating form can cover everything. A sample of the behaviors is the best that can be achieved, and a good form focuses on those behaviors that controllers themselves have identified as the most relevant in terms of their overall performance. Most controller performance is at or above the minimum standards regarding safety and efficiency. The goal of the rating system is to differentiate performance above this minimum. The lowest rating should be assigned for meeting minimum standards and also for anything below the minimum since this should be a rare event. It is important for the observer/rater to feel comfortable using the entire scale and to understand that all ratings should be based on behavior that is actually observed.

Rating Scale Descriptors

Remove this Page and keep it available while doing ratings

Scale	Quality	Supplementary
1	**Least Effective**	Lacks confidence, Indecisive, Inefficient, Disorganized, Behind the power curve, Rough, Leaves some tasks incomplete, Makes mistakes
2	**Poor**	May issue conflicting instructions, Doesn't plan completely
3	**Fair**	Distracted between tasks
4	**Low Satisfactory**	Postpones routine actions
5	**Satisfactory**	Knows the job fairly well
6	**Good**	Works steadily, Solves most problems
7	**Very Good**	Knows the job thoroughly, Plans well
8	**Most Effective**	Confident, Decisive, Efficient, Organized, Ahead of the power curve, Smooth, Completes all necessary tasks, Makes no mistakes

I – MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW
II – MAINTAINING ATTENTION AND SITUATION AWARENESS
III – PRIORITIZING
IV – PROVIDING CONTROL INFORMATION
V – TECHNICAL KNOWLEDGE
VI – COMMUNICATING
VII – SECTOR MANAGEMENT

I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW								
1. Maintaining Separation and Resolving Potential Conflicts	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• using control instructions that maintain appropriate aircraft and • detecting and resolving impending conflicts early • recognizing the need for speed restrictions and wake turbulence								
2. Sequencing Aircraft Efficiently	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• using efficient and orderly spacing techniques for arrival, departure, • maintaining safe arrival and departure intervals that minimize delays								
3. Using Control Instructions Effectively/Efficiently	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• providing accurate navigational assistance to pilots • issuing efficient clearances that require few or no additional • ensuring clearances require minimum necessary flight path changes								
4. Overall Safe and Efficient Traffic Flow Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

II - MAINTAINING ATTENTION AND SITUATION AWARENESS								
5. Maintaining Awareness of Aircraft Positions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• avoiding fixation on one area of the sector when other areas need • using scanning patterns that monitor all aircraft in the sector								
6. Giving and Taking Handoffs in a Timely Manner	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• ensuring that handoffs are initiated in a timely manner • ensuring that handoffs are accepted in a timely manner • ensuring that handoffs are made according to procedures								
7. Ensuring Positive Control	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• tailoring control actions to situation • using effective procedures for handling heavy, emergency, and								
8. Detecting Pilot Deviations from Control Instructions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• ensuring that pilots follow assigned clearances correctly • correcting pilot deviations in a timely manner								
9. Correcting Own Errors in a Timely Manner	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
• acting quickly to correct errors • changing an issued clearance when necessary to expedite traffic flow								
10. Overall Attention and Situation Awareness Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

III – PRIORITIZING								
11. Taking Actions in an Appropriate Order of Importance • resolving situations that need immediate attention before handling • issuing control instructions in a prioritized, structured, and timely	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12. Preplanning Control Actions • scanning adjacent sectors to plan for future and conflicting traffic	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
13. Handling Control Tasks for Several Aircraft • shifting control tasks between several aircraft when necessary • communicating in a timely manner while sharing time with other	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
14. Marking Flight Progress Strips while Performing Other Tasks • marking flight progress strips accurately while talking or performing • keeping flight progress strips current	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
15. Overall Prioritizing Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

IV – PROVIDING CONTROL INFORMATION								
16. Providing Essential Air Traffic Control Information • providing mandatory services and advisories to pilots in a timely • exchanging essential information	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
17. Providing Additional Air Traffic Control Information • providing additional services when workload permits • exchanging additional information when necessary	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
18. Providing Coordination • providing effective and timely coordination • using proper point-out procedures	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
19. Overall Providing Control Information Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

V – TECHNICAL KNOWLEDGE								
20. Showing Knowledge of LOAs and SOPs • controlling traffic in accordance with current LOAs and SOPs • performing handoff procedures correctly	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
21. Showing Knowledge of Aircraft Capabilities and Limitations • using appropriate speed, vectoring, and/or altitude assignments to • issuing clearances that are within aircraft performance parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
22. Showing Effective Use of Equipment • updating data blocks • using equipment capabilities properly	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
23. Overall Technical Knowledge Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

VI – COMMUNICATING								
24. Using Prescribed Phraseology • using words and phrases specified in the FAA 7110.65 • using phraseology that is appropriate for the situation • using minimum necessary verbiage	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
25. Communicating Clearly and Efficiently • speaking at the proper volume and rate for pilots to understand • speaking fluently while scanning or performing other tasks • ensuring clearance delivery is complete, correct and timely • speaking with confident, authoritative tone of voice	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
26. Listening to Pilot Readbacks and Requests • correcting pilot readback errors • acknowledging pilot or other controller requests promptly • processing requests correctly in a timely manner	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
27. Overall Communicating Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

Appendix F: Front Line Manager Form

Date: _____ Scenario: _____ Start Time: _____

UAS Call Sign _____ Event _____

1. What is the **TIME OF THE EVENT**?

   SIM Time _____

2. What is the **LOCATION OF THE EVENT**?

   _____

   _____

   _____

3. **ACTIONS** taken by the FLM:

   ☐ Coordination (Communication) with Air Traffic Controller

   ☐ Coordination (Communication) with Pilot in Command (GCS)

   ☐ Coordination (Communication) with the facility(ies)

4. **EXPLAIN ACTIONS** in detail. Include content of action (communication/coordination) as well, as how the information was passed from ATC to PIC or PIC to ATC**.**

_____

_____

_____

_____

_____

_____

_____

_____

This page intentionally left blank.

Appendix G: Results – Configuration 1, Grove

Table G-1 Summary of Post-Scenario Questionnaire Data (Config 1, Grove)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away
NASA-TLX, Mental Demand	5.83	6.58	6.08	6.00
NASA-TLX, Physical Demand	3.42	3.83	3.58	2.92
NASA-TLX, Temporal Demand	4.75	6.00	5.33	5.42
NASA-TLX, Performance	7.08	6.42	7.17	7.67
NASA-TLX, Effort	6.42	7.25	6.58	6.58
NASA-TLX, Frustration	3.25	4.58	4.67	3.75
Overall effectiveness of sector management and services provided	6.92	5.83	6.92	6.92
Overall Safety	7.83	5.33	7.42	7.25
Overall Efficiency	6.92	6.08	6.42	7.33
Ability to identify and resolve aircraft conflicts safely	5.33	4.25	5.42	5.42
Ability to move aircraft efficiently through the sector	5.00	4.58	5.25	5.08
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	3.45	4.36	4.18
Overall Workload	6.58	6.92	6.75	6.67
Workload due to controller-to-pilot communications	6.00	5.67	5.75	6.33
Workload due to controller-to-front line manager communications	1.00	2.18	3.91	2.00
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.00	4.45	4.45
Overall level of SA	7.42	7.17	7.50	7.33
SA for detecting aircraft conflicts	7.58	7.08	7.33	7.50
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.45	4.64	4.82
Overall performance of the simulation pilots	7.75	8.00	7.33	8.08
Overall difficulty of the scenario	6.36	7.45	6.55	6.36

Table G-2 Summary of Safety & Efficiency Data (Config 1, Grove)

Safety & Efficiency	Baseline	Lost Link	Lost Comm	Fly-away
LOS	0.50	0.71	0.83	0.25
LOS-MVA	0.00	0.00	0.00	0.00
HFR	0.00	0.00	0.00	0.00
Departure Delay	0.00	0.00	0.00	0.00
Arrival Delay	0.25	1.25	0.83	0.67

Table G-3 Summary of Time/Distance/Transmissions Data (Config 1, Grove)

Time/Distance/Transmissions	Baseline	Lost Link	Lost Comm	Fly-away
Flights	38.91	38.73	38.64	39.09
Flights-Total Time, Seconds	12,996.00	12,286.27	12,933.00	12,822.36
Flights-Mean Time, Seconds	334.87	316.79	335.50	328.62
Flights-Total Distance, NM	544.74	517.37	540.49	526.83
Flights-Mean Distance, NM	14.04	13.34	14.02	13.50
PTTs	123.64	130.45	121.64	123.91
PTTs-Total Time, Seconds	539.53	542.04	513.72	532.28
PTTs-Mean Time, Seconds	4.39	4.18	4.24	4.30

Table G-4 Summary of WAK Data (Config 1, Grove)

WAK Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Interval #1, 00:00-04:00	1.58	1.67	1.58	1.50
Interval #2, 04:00-08:00	1.73	2.09	2.00	2.27
Interval #3, 08:00-12:00	2.00	2.18	2.55	2.18
Interval #4, 12:00-16:00	2.20	2.40	2.50	2.20
Interval #5, 16:00-20:00	2.27	2.73	2.64	2.00
Interval #6, 20:00-24:00	2.33	2.42	2.25	2.17
Interval #7, 24:00-28:00	2.44	2.78	2.56	2.44
Mean WAK Rating	2.01	2.27	2.26	2.02

Table G-5 Summary of Observer Ratings Data (Config 1, Grove)

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Maintaining Separation and Resolving Potential Conflicts	5.75	4.92	5.67	5.42
Sequencing Aircraft Efficiently	5.67	5.50	5.58	5.42
Using Control Instructions Effectively/Efficiently	5.42	5.67	5.42	5.42
Overall Safe and Efficient Traffic Flow Scale Rating	5.55	5.36	5.36	5.36
Maintaining Awareness of Aircraft Positions	5.67	5.83	5.75	5.42
Giving and Taking Handoffs in a Timely Manner	5.36	5.36	5.27	5.27
Ensuring Positive Control	5.67	5.42	4.83	5.42
Detecting Pilot Deviations from Control Instructions	5.75	5.25	5.42	5.42
Correcting Own Errors in a Timely Manner	5.55	5.09	5.00	5.45
Overall Attention and SA Scale Rating	5.75	5.42	5.42	5.42
Taking Actions in an Appropriate Order of Importance	5.67	5.67	5.25	5.25
Preplanning Control Actions	5.58	5.50	5.50	5.33
Handling Control Tasks for Several Aircraft	5.58	5.67	5.67	5.50
Marking Flight Progress Strips while Performing Other Tasks	N/A	6.00	6.00	6.00
Overall Prioritizing Scale Rating	5.45	5.45	5.45	5.55
Providing Essential Air Traffic Control Information	5.75	5.08	5.33	5.25
Providing Additional Air Traffic Control Information	5.83	5.08	5.17	5.08
Providing Coordination	5.67	5.33	5.08	5.42
Overall Providing Control Information Scale Rating	5.83	5.00	5.17	5.33
Showing Knowledge of LOAs and SOPs	5.64	5.36	5.18	5.00
Showing Knowledge of Aircraft Capabilities and Limitations	5.45	5.27	5.09	4.91

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Showing Effective Use of Equipment	5.64	5.73	5.73	5.36
Overall Technical Knowledge Scale Rating	5.55	5.45	5.36	4.91
Using Prescribed Phraseology	5.18	5.09	5.36	5.27
Communicating Clearly and Efficiently	5.00	5.00	4.91	5.00
Listening to Pilot Readbacks and Requests	5.36	5.18	5.09	5.45
Overall Communicating Scale Rating	5.27	5.09	5.18	5.27

Appendix H: Results – Configuration 1, Grove Handoff

Table H-1 Summary of Post-Scenario Questionnaire Data (Config 1, Grove HO)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away
NASA-TLX, Mental Demand	4.42	5.92	5.25	5.00
NASA-TLX, Physical Demand	2.92	3.75	3.67	3.25
NASA-TLX, Temporal Demand	3.25	5.25	4.92	4.08
NASA-TLX, Performance	7.75	6.75	6.83	6.92
NASA-TLX, Effort	4.33	5.58	5.42	5.25
NASA-TLX, Frustration	1.75	4.00	3.75	3.17
Overall effectiveness of sector management and services provided	7.08	6.25	6.33	6.08
Overall Safety	8.08	6.25	7.17	7.17
Overall Efficiency	7.33	6.17	6.58	6.25
Ability to identify and resolve aircraft conflicts safely	4.92	4.25	5.17	4.75
Ability to move aircraft efficiently through the sector	4.82	3.55	4.73	4.36
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	3.25	4.33	3.75
Overall Workload	4.83	6.58	5.83	5.92
Workload due to controller-to-pilot communications	3.73	3.73	4.45	3.91
Workload due to controller-to-front line manager communications	1.00	3.90	5.40	4.30
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	3.33	4.50	3.92
Overall level of SA	7.58	7.25	7.42	7.25
SA for detecting aircraft conflicts	8.00	7.42	7.42	7.33
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.25	4.75	4.00
Overall performance of the simulation pilots	8.08	7.50	7.50	7.92
Overall difficulty of the scenario	5.25	6.58	6.33	6.67

Table H-2 Summary of WAK Data (Config 1, Grove HO)

WAK Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Interval #1, 00:00-04:00	1.27	1.18	1.09	1.18
Interval #2, 04:00-08:00	1.45	1.55	1.82	1.45
Interval #3, 08:00-12:00	1.60	1.40	2.10	1.70
Interval #4, 12:00-16:00	1.80	1.90	2.40	1.70
Interval #5, 16:00-20:00	1.90	2.30	2.20	1.80
Interval #6, 20:00-24:00	2.00	2.44	2.00	1.78
Interval #7, 24:00-28:00	2.20	2.50	2.00	1.90
Mean WAK Rating	1.75	1.92	1.89	1.71

Table H-3 Summary of Observer Ratings Data (Config 1, Grove HO)

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Maintaining Separation and Resolving Potential Conflicts	5.82	5.36	5.91	5.82
Sequencing Aircraft Efficiently	5.82	5.36	5.82	5.82
Using Control Instructions Effectively/Efficiently	5.82	5.45	5.91	5.73
Overall Safe and Efficient Traffic Flow Scale Rating	5.91	5.45	5.91	5.91
Maintaining Awareness of Aircraft Positions	5.73	5.45	6.00	5.82
Giving and Taking Handoffs in a Timely Manner	5.91	5.82	5.91	5.82
Ensuring Positive Control	5.73	5.36	5.91	5.82
Detecting Pilot Deviations from Control Instructions	5.73	5.36	5.91	5.82
Correcting Own Errors in a Timely Manner	5.82	5.55	5.91	5.82
Overall Attention and SA Scale Rating	5.73	5.55	6.00	5.91
Taking Actions in an Appropriate Order of Importance	5.91	5.64	5.82	5.82
Preplanning Control Actions	5.82	5.55	5.64	5.82
Handling Control Tasks for Several Aircraft	5.73	5.73	5.82	5.82
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away
Overall Prioritizing Scale Rating	5.70	5.50	5.70	5.70
Providing Essential Air Traffic Control Information	5.82	5.73	5.82	5.91
Providing Additional Air Traffic Control Information	5.45	5.36	5.55	5.55
Providing Coordination	5.82	5.45	5.73	5.82
Overall Providing Control Information Scale Rating	5.70	5.40	5.60	5.70
Showing Knowledge of LOAs and SOPs	6.10	5.80	5.80	5.90
Showing Knowledge of Aircraft Capabilities and Limitations	6.00	5.55	5.82	5.82
Showing Effective Use of Equipment	5.91	5.55	5.82	5.82
Overall Technical Knowledge Scale Rating	6.09	5.73	5.91	5.91
Using Prescribed Phraseology	5.82	5.18	5.64	5.73
Communicating Clearly and Efficiently	5.82	5.55	5.82	5.82
Listening to Pilot Readbacks and Requests	5.82	5.45	5.73	5.82
Overall Communicating Scale Rating	5.82	5.55	5.82	5.91

This page intentionally left blank.

Appendix I: Results – Configuration 2, Richmond

Table I-1 Summary of Post-Scenario Questionnaire Data (Config 2, Richmond)

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
NASA-TLX, Mental Demand	5.25	7.58	6.83	7.50	6.92
NASA-TLX, Physical Demand	3.92	5.25	4.83	4.92	5.58
NASA-TLX, Temporal Demand	5.09	6.91	6.27	6.64	6.27
NASA-TLX, Performance	7.00	5.83	7.08	6.42	6.67
NASA-TLX, Effort	5.75	7.33	7.17	7.17	7.08
NASA-TLX, Frustration	3.92	6.17	5.17	5.67	5.00
Overall effectiveness of sector management and services provided	7.00	5.82	7.18	6.27	5.91
Overall Safety	8.00	6.45	7.64	6.73	6.91
Overall Efficiency	6.91	6.27	6.55	6.27	6.09
Ability to identify and resolve aircraft conflicts safely	5.45	4.18	5.00	4.82	5.00
Ability to move aircraft efficiently through the sector	5.64	4.18	4.91	4.91	5.00
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	3.82	4.73	5.09	4.27
Overall Workload	6.25	7.92	7.33	7.75	7.33
Workload due to controller-to-pilot communications	5.18	7.18	6.73	7.36	6.82
Workload due to controller-to-front line manager communications	1.00	1.55	1.45	2.18	1.64
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.17	4.58	5.00	4.08
Overall level of SA	7.73	6.64	7.55	6.91	6.82
SA for detecting aircraft conflicts	7.82	6.45	7.45	6.73	7.09
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.45	5.45	5.09	5.09

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Overall performance of the simulation pilots	7.64	6.09	6.91	6.27	6.45
Overall difficulty of the scenario	5.73	7.73	6.91	7.36	7.27

Table I-2 Summary of Safety & Efficiency Data (Config 2, Richmond)

Safety & Efficiency	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
LOS	0.25	0.75	0.33	0.50	0.50
LOS-MVA	0.00	0.00	0.00	0.00	0.08
HFR	0.08	1.17	0.50	0.33	1.58
Departure Delay	0.17	3.50	0.00	0.17	2.92
Arrival Delay	0.00	0.00	0.00	0.00	0.25

Table I-3 Summary of Time/Distance/Transmissions Data (Config 2, Richmond)

Time/Distance/ \Transmissions	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Flights	69.27	69.73	69.36	69.45	67.36
Flights-Total Time, Seconds	19,202.00	20,055.91	19,326.45	19,324.82	19,250.82
Flights-Mean Time, Seconds	277.17	287.64	278.74	278.18	285.83
Flights-Total Distance, NM	1,085.14	1,108.80	1,085.25	1,072.64	1,067.37
Flights-Mean Distance, NM	15.66	15.90	15.65	15.44	15.86
PTTs	146.00	155.55	150.73	155.27	151.73
PTTs-Total Time, Seconds	573.21	602.85	595.41	597.57	586.77
PTTs-Mean Time, Seconds	3.92	3.89	3.95	3.84	3.86

Table I-4 Summary of WAK Data (Config 2, Richmond)

WAK Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Interval #1, 00:00-04:00	1.75	2.08	2.00	2.08	2.08
Interval #2, 04:00-08:00	3.18	3.64	3.55	3.55	3.36
Interval #3, 08:00-12:00	3.70	4.30	4.10	4.10	3.80
Interval #4, 12:00-16:00	3.50	4.20	4.10	4.20	4.20
Interval #5, 16:00-20:00	3.40	4.30	3.90	3.90	3.80
Interval #6, 20:00-24:00	2.30	3.30	3.10	2.50	2.80
Interval #7, 24:00-28:00	1.82	2.36	2.00	2.27	2.09
Mean WAK Rating	2.75	3.44	3.23	3.25	3.18

Table I-5 Summary of Observer Ratings Data (Config 2, Richmond)

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Maintaining Separation and Resolving Potential Conflicts	6.08	5.75	6.08	6.00	6.17
Sequencing Aircraft Efficiently	6.25	6.00	6.17	5.92	6.17
Using Control Instructions Effectively/Efficiently	6.00	5.83	6.08	5.83	6.00
Overall Safe and Efficient Traffic Flow Scale Rating	6.64	5.91	6.55	6.27	6.55
Maintaining Awareness of Aircraft Positions	6.33	5.75	6.42	5.83	6.17
Giving and Taking Handoffs in a Timely Manner	6.25	6.17	6.33	6.08	6.17
Ensuring Positive Control	6.18	5.82	6.45	6.09	6.09
Detecting Pilot Deviations from Control Instructions	5.80	6.00	5.60	5.90	5.80
Correcting Own Errors in a Timely Manner	6.17	6.00	6.17	5.83	5.92
Overall Attention and SA Scale Rating	6.50	5.83	6.33	6.17	6.42
Taking Actions in an Appropriate Order of Importance	6.25	5.75	6.33	6.25	6.08

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Preplanning Control Actions	6.25	5.58	6.08	5.75	6.08
Handling Control Tasks for Several Aircraft	6.25	5.92	6.25	6.00	5.83
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A	N/A
Overall Prioritizing Scale Rating	6.42	5.67	6.42	6.25	6.25
Providing Essential Air Traffic Control Information	6.33	5.67	6.08	6.00	6.00
Providing Additional Air Traffic Control Information	6.08	5.50	5.83	6.00	5.83
Providing Coordination	6.25	5.75	5.92	6.17	6.00
Overall Providing Control Information Scale Rating	6.42	5.58	6.08	6.33	6.25
Showing Knowledge of LOAs and SOPs	6.33	6.25	6.08	6.25	6.25
Showing Knowledge of Aircraft Capabilities and Limitations	6.25	6.33	6.33	6.25	6.00
Showing Effective Use of Equipment	6.18	6.18	5.91	5.91	6.00
Overall Technical Knowledge Scale Rating	6.42	6.33	6.17	6.42	6.42
Using Prescribed Phraseology	6.00	6.08	5.83	5.92	6.00
Communicating Clearly and Efficiently	5.83	5.92	5.58	5.58	5.67
Listening to Pilot Readbacks and Requests	6.00	6.17	5.75	5.92	5.58
Overall Communicating Scale Rating	6.17	6.25	5.92	5.92	6.00

Appendix J: Results – Configuration 2, Sutro

Table J-1 Summary of Post-Scenario Questionnaire Data (Config 2, Sutro)

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
NASA-TLX, Mental Demand	4.08	5.67	4.33	3.75	5.92
NASA-TLX, Physical Demand	3.50	3.83	3.25	2.92	4.58
NASA-TLX, Temporal Demand	3.58	4.75	3.58	3.50	5.17
NASA-TLX, Performance	7.58	7.17	7.08	7.42	5.83
NASA-TLX, Effort	4.17	5.33	4.42	3.58	5.58
NASA-TLX, Frustration	3.25	3.08	2.92	2.58	4.50
Overall effectiveness of sector management and services provided	7.55	7.09	7.18	7.45	6.36
Overall Safety	8.64	7.64	7.82	8.00	6.73
Overall Efficiency	8.27	7.09	7.73	7.82	6.64
Ability to identify and resolve aircraft conflicts safely	5.58	5.67	5.00	5.25	4.92
Ability to move aircraft efficiently through the sector	5.64	5.55	5.18	5.09	4.82
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	4.60	5.10	5.00	4.30
Overall Workload	4.18	5.64	4.45	4.27	5.64
Workload due to controller-to-pilot communications	3.64	4.73	3.55	3.00	4.00
Workload due to controller-to-front line manager communications	1.36	2.82	1.36	1.27	3.18
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	5.00	5.00	5.11	4.44
Overall level of SA	7.08	7.58	7.42	7.08	7.25
SA for detecting aircraft conflicts	7.33	7.67	7.58	7.67	7.00
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.70	5.40	5.00	4.90

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Overall performance of the simulation pilots	8.00	7.50	8.42	8.42	7.42
Overall difficulty of the scenario	3.58	4.83	3.50	3.75	5.83

Table J-2 Summary of Safety & Efficiency Data (Config 2, Sutro)

Safety & Efficiency	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
LOS	0.00	0.00	0.08	0.00	0.00
LOS-MVA	0.00	0.00	0.00	0.00	0.00
HFR	0.00	1.00	0.42	0.00	1.67
Departure Delay	0.00	1.83	0.00	0.00	3.33
Arrival Delay	0.00	0.00	0.00	0.00	0.00

Table J-3 Summary of Time/Distance/Transmissions Data (Config 2, Sutro)

Time/Distance/ Transmissions	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Flights	52.55	52.82	52.73	52.55	50.82
Flights-Total Time, Seconds	12,344.82	12,174.55	12,393.82	12,328.27	11,710.73
Flights-Mean Time, Seconds	234.95	230.54	235.07	234.56	230.48
Flights-Total Distance, NM	658.53	641.19	655.17	655.70	616.86
Flights-Mean Distance, NM	12.53	12.14	12.43	12.48	12.15
PTTs	101.09	103.82	99.27	102.45	103.00
PTTs-Total Time, Seconds	389.61	387.13	387.40	396.24	389.28
PTTs-Mean Time, Seconds	3.85	3.72	3.90	3.87	3.77

Table J-4 Summary of WAK Data (Config 2, Sutro)

WAK Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Interval #1, 00:00-04:00	1.18	1.09	1.18	1.18	1.36
Interval #2, 04:00-08:00	1.64	1.73	1.36	1.73	1.55
Interval #3, 08:00-12:00	2.00	1.82	1.27	1.82	1.82
Interval #4, 12:00-16:00	1.73	1.55	1.45	1.64	2.00
Interval #5, 16:00-20:00	2.33	1.78	2.00	2.33	3.00
Interval #6, 20:00-24:00	1.78	2.00	1.89	1.67	2.78
Interval #7, 24:00-28:00	1.55	2.00	1.64	1.91	2.64
Mean WAK Rating	1.74	1.70	1.52	1.75	2.11

Table J-5 Summary of Observer Ratings Data (Config 2, Sutro)

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Maintaining Separation and Resolving Potential Conflicts	6.08	5.75	6.08	6.00	6.17
Sequencing Aircraft Efficiently	6.25	6.00	6.17	5.92	6.17
Using Control Instructions Effectively/Efficiently	6.00	5.83	6.08	5.83	6.00
Overall Safe and Efficient Traffic Flow Scale Rating	6.64	5.91	6.55	6.27	6.55
Maintaining Awareness of Aircraft Positions	6.33	5.75	6.42	5.83	6.17
Giving and Taking Handoffs in a Timely Manner	6.25	6.17	6.33	6.08	6.17
Ensuring Positive Control	6.18	5.82	6.45	6.09	6.09
Detecting Pilot Deviations from Control Instructions	5.80	6.00	5.60	5.90	5.80
Correcting Own Errors in a Timely Manner	6.17	6.00	6.17	5.83	5.92
Overall Attention and SA Scale Rating	6.50	5.83	6.33	6.17	6.42
Taking Actions in an Appropriate Order of Importance	6.25	5.75	6.33	6.25	6.08
Preplanning Control Actions	6.25	5.58	6.08	5.75	6.08

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Handling Control Tasks for Several Aircraft	6.25	5.92	6.25	6.00	5.83
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A	N/A
Overall Prioritizing Scale Rating	6.42	5.67	6.42	6.25	6.25
Providing Essential Air Traffic Control Information	6.33	5.67	6.08	6.00	6.00
Providing Additional Air Traffic Control Information	6.08	5.50	5.83	6.00	5.83
Providing Coordination	6.25	5.75	5.92	6.17	6.00
Overall Providing Control Information Scale Rating	6.42	5.58	6.08	6.33	6.25
Showing Knowledge of LOAs and SOPs	6.33	6.25	6.08	6.25	6.25
Showing Knowledge of Aircraft Capabilities and Limitations	6.25	6.33	6.33	6.25	6.00
Showing Effective Use of Equipment	6.18	6.18	5.91	5.91	6.00
Overall Technical Knowledge Scale Rating	6.42	6.33	6.17	6.42	6.42
Using Prescribed Phraseology	6.00	6.08	5.83	5.92	6.00
Communicating Clearly and Efficiently	5.83	5.92	5.58	5.58	5.67
Listening to Pilot Readbacks and Requests	6.00	6.17	5.75	5.92	5.58
Overall Communicating Scale Rating	6.17	6.25	5.92	5.92	6.00

Appendix K: Results – Configuration 2, Coordinator (CI)

Table K-1 Summary of Post-Scenario Questionnaire Data (Config 2, CI)

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
NASA-TLX, Mental Demand	4.58	6.67	5.83	5.92	6.75
NASA-TLX, Physical Demand	4.25	5.83	5.25	4.92	5.58
NASA-TLX, Temporal Demand	4.42	5.92	5.00	5.42	5.75
NASA-TLX, Performance	7.92	7.17	7.33	6.50	6.42
NASA-TLX, Effort	5.08	6.33	5.33	6.00	6.50
NASA-TLX, Frustration	3.25	4.83	3.92	4.42	4.92
Overall effectiveness of sector management and services provided	7.82	6.73	7.36	6.45	6.55
Overall Safety	8.09	6.91	8.36	7.09	6.55
Overall Efficiency	7.73	6.64	7.64	6.45	6.55
Ability to identify and resolve aircraft conflicts safely	5.33	4.67	5.17	4.75	4.92
Ability to move aircraft efficiently through the sector	5.45	5.09	5.09	5.09	4.55
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	4.25	4.17	4.42	3.58
Overall Workload	5.25	6.92	6.00	6.83	7.50
Workload due to controller-to-pilot communications	3.40	4.00	3.50	4.60	5.80
Workload due to controller-to-front line manager communications	1.27	3.27	2.91	3.00	3.18
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.50	4.17	4.00	3.67
Overall level of SA	7.83	6.67	7.33	6.75	7.25
SA for detecting aircraft conflicts	7.55	5.91	6.91	7.09	7.36
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.42	4.83	5.00	5.42

Post-Scenario Questionnaire	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Overall performance of the simulation pilots	7.90	6.00	7.80	6.90	6.40
Overall difficulty of the scenario	5.00	7.27	6.27	6.73	7.45

Table K-2 Summary of WAK Data (Config 2, CI)

WAK Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Interval #1, 00:00-04:00	1.33	1.25	1.83	1.50	1.25
Interval #2, 04:00-08:00	2.36	2.82	2.82	2.64	2.45
Interval #3, 08:00-12:00	2.45	3.82	3.27	3.18	2.64
Interval #4, 12:00-16:00	3.00	4.00	3.45	3.64	3.09
Interval #5, 16:00-20:00	2.67	3.67	3.44	3.33	4.11
Interval #6, 20:00-24:00	2.10	3.50	2.60	2.50	3.40
Interval #7, 24:00-28:00	1.36	2.36	1.73	2.18	2.64
Mean WAK Rating	2.18	3.12	2.74	2.74	2.76

Table K-3 Summary of Observer Ratings Data (Config 2, CI)

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Maintaining Separation and Resolving Potential Conflicts	5.82	5.36	5.91	5.82	5.82
Sequencing Aircraft Efficiently	5.82	5.36	5.82	5.82	5.55
Using Control Instructions Effectively/Efficiently	5.82	5.45	5.91	5.73	5.36
Overall Safe and Efficient Traffic Flow Scale Rating	5.91	5.45	5.91	5.91	5.55
Maintaining Awareness of Aircraft Positions	5.73	5.45	6.00	5.82	5.64
Giving and Taking Handoffs in a Timely Manner	5.91	5.82	5.91	5.82	5.82
Ensuring Positive Control	5.73	5.36	5.91	5.82	5.64
Detecting Pilot Deviations from Control Instructions	5.73	5.36	5.91	5.82	5.73
Correcting Own Errors in a Timely Manner	5.82	5.55	5.91	5.82	5.73

Observer Ratings	Baseline	Lost Link-Cruise	Lost Link-Departure	Flight Termination	Engine Failure
Overall Attention and SA Scale Rating	5.73	5.55	6.00	5.91	5.73
Taking Actions in an Appropriate Order of Importance	5.91	5.64	5.82	5.82	5.45
Preplanning Control Actions	5.82	5.55	5.64	5.82	5.45
Handling Control Tasks for Several Aircraft	5.73	5.73	5.82	5.82	5.91
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A	N/A
Overall Prioritizing Scale Rating	5.70	5.50	5.70	5.70	5.60
Providing Essential Air Traffic Control Information	5.82	5.73	5.82	5.91	5.64
Providing Additional Air Traffic Control Information	5.45	5.36	5.55	5.55	5.27
Providing Coordination	5.82	5.45	5.73	5.82	5.73
Overall Providing Control Information Scale Rating	5.70	5.40	5.60	5.70	5.50
Showing Knowledge of LOAs and SOPs	6.10	5.80	5.80	5.90	5.10
Showing Knowledge of Aircraft Capabilities and Limitations	6.00	5.55	5.82	5.82	4.91
Showing Effective Use of Equipment	5.91	5.55	5.82	5.82	5.73
Overall Technical Knowledge Scale Rating	6.09	5.73	5.91	5.91	5.27
Using Prescribed Phraseology	5.82	5.18	5.64	5.73	5.45
Communicating Clearly and Efficiently	5.82	5.55	5.82	5.82	5.73
Listening to Pilot Readbacks and Requests	5.82	5.45	5.73	5.82	5.73
Overall Communicating Scale Rating	5.82	5.55	5.82	5.91	5.64

This page intentionally left blank.

Appendix L: Results – Configuration 2A, Richmond

For Configuration 2A, the research team took advantage of a target of opportunity for additional runs. Therefore, a sub-analysis of this departure configuration was conducted with a smaller sample size. The scenarios conducted for this sub-analysis were lost link-cruise, lost link-departure, flight termination, engine failure, lost link-multiple, lost comm, and fly-away. As the sample size for this sub-analysis was smaller than the analysis for the core scenarios, the results for these scenarios are provided in Table L-1 as a supplement to the primary findings.

Table L-1 Summary of Post-Scenario Questionnaire Data (Config 2A, Richmond)

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
NASA-TLX, Mental Demand	5.75	8.00	6.75	8.00	6.50	7.25	7.00	7.50
NASA-TLX, Physical Demand	3.00	4.50	3.50	3.50	4.00	5.75	4.50	4.25
NASA-TLX, Temporal Demand	5.50	6.50	5.75	6.75	5.25	7.00	6.25	6.50
NASA-TLX, Performance	6.75	6.75	6.75	6.50	7.75	7.25	6.75	6.50
NASA-TLX, Effort	5.75	7.50	7.50	8.00	6.00	6.75	6.75	7.50
NASA-TLX, Frustration	4.50	6.25	6.00	6.50	4.50	5.25	4.75	5.50
Overall effectiveness of sector management and services provided	6.75	5.75	7.75	6.25	6.25	6.00	6.50	5.75
Overall Safety	8.25	7.00	7.75	6.75	7.25	6.75	7.75	6.50
Overall Efficiency	6.50	5.75	6.25	6.00	6.00	5.50	7.00	5.50
Ability to identify and resolve aircraft conflicts safely	4.33	3.33	4.67	3.33	4.00	5.33	5.00	3.00
Ability to move aircraft efficiently through the sector	5.00	4.00	4.67	4.00	3.67	5.67	4.67	3.33
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	5.33	5.00	5.33	4.67	4.67	4.00	2.00
Overall Workload	6.50	8.50	7.50	8.25	7.25	7.75	8.00	8.25

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Workload due to controller-to-pilot communications	5.00	8.00	7.33	8.33	5.33	5.00	6.33	7.67
Workload due to controller-to-front line manager communications	1.00	1.00	1.67	2.67	1.00	2.33	1.33	1.33
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	5.00	5.00	5.25	5.00	5.50	4.25	3.25
Overall level of SA	7.50	6.00	6.00	5.50	6.50	5.00	7.00	5.50
SA for detecting aircraft conflicts	7.50	6.00	7.00	5.50	7.00	6.00	7.00	5.00
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.50	5.00	3.50	4.00	5.50	5.00	2.50
Overall performance of the simulation pilots	8.00	6.00	5.67	5.00	6.00	5.67	6.67	4.33
Overall difficulty of the scenario	5.67	8.33	7.00	7.33	6.67	7.00	7.33	8.00

Table L-2 Summary of Safety & Efficiency Data (Config 2A, Richmond)

Safety & Efficiency	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
LOS	0.75	1.25	1.00	0.75	1.00	1.25	0.25	0.75
LOS-MVA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HFR	0.25	1.25	0.50	1.00	2.00	0.75	1.50	1.75
Departure Delay	0.50	3.75	0.00	0.50	3.75	2.00	3.25	4.00
Arrival Delay	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00

Table L-3 Summary of Time/Distance/Transmissions Data (Config 2A, Richmond)

Time/Distance/ Transmissions	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Flights	69	70	69	70	66	70	63	62

Time/Distance/ Transmissions	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Flights-Total Time, Seconds	19,043	20,704	19,336	19,698	19,145	20,584	17,776	18,220
Flights-Mean Time, Seconds	276	294	282	281	288	294	282	296
Flights-Total Distance, Nautical Miles (NM)	1,067	1,135	1,085	1,094	1,057	1,114	996	1,008
Flights-Mean Distance, NM	15	16	16	16	16	16	16	16
PTTs	150	152	153	165	155	150	143	149
PTTs-Total Time, Seconds	630	638	667	696	669	617	623	644
PTTs-Mean Time, Seconds	4	4	4	4	4	4	4	4

Table L-4 Summary of WAK Data (Config 2A, Richmond)

WAK Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Interval #1, 00:00-04:00	2.00	2.50	1.75	2.00	2.25	1.75	1.75	2.00
Interval #2, 04:00-08:00	3.50	4.25	3.50	3.75	3.75	2.75	3.00	3.50
Interval #3, 08:00-12:00	3.67	5.00	4.67	4.67	3.67	4.00	5.00	4.33
Interval #4, 12:00-16:00								
Interval #5, 16:00-20:00	4.00	4.33	4.67	4.33	4.00	4.67	4.33	4.33
Interval #6, 20:00-24:00								
Interval #7, 24:00-28:00	2.00	2.50	1.50	3.00	1.50	2.50	2.50	2.00
Mean WAK Rating	3.00	4.04	3.38	3.62	3.24	3.27	3.82	3.60

Table L-5 Summary of Observer Ratings Data (Config 2A, Richmond)

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Com m	Fly-away

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Maintaining Separation and Resolving Potential Conflicts	4.75	5.25	5.25	5.50	5.50	6.00	5.25	5.00
Sequencing Aircraft Efficiently	5.25	5.50	5.50	5.25	5.50	5.75	5.25	5.00
Using Control Instructions Effectively/Efficiently	5.00	5.25	5.50	5.25	5.25	5.75	5.25	4.75
Overall Safe and Efficient Traffic Flow Scale Rating	5.67	5.67	5.67	5.33	5.67	6.67	5.33	5.33
Maintaining Awareness of Aircraft Positions	5.25	5.50	5.25	5.50	5.50	6.25	5.25	5.25
Giving and Taking Handoffs in a Timely Manner	5.25	5.50	5.25	5.50	5.50	6.25	5.25	5.25
Ensuring Positive Control	5.25	5.25	5.50	5.50	5.50	6.25	5.25	5.25
Detecting Pilot Deviations from Control Instructions	4.00	5.00	5.00	5.00	4.67	5.33	4.67	4.67
Correcting Own Errors in a Timely Manner	5.00	5.50	5.25	5.25	5.25	5.25	5.25	5.00
Overall Attention and SA Scale Rating	5.25	5.50	5.25	5.50	5.50	5.75	5.25	5.25
Taking Actions in an Appropriate Order of Importance	5.00	5.25	5.25	5.50	5.25	5.50	5.25	5.25
Preplanning Control Actions	5.25	4.75	5.00	5.25	5.50	5.75	5.25	5.50
Handling Control Tasks for Several Aircraft	4.75	5.50	5.25	5.50	5.25	5.25	5.25	5.25

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Overall Prioritizing Scale Rating	5.00	5.00	5.25	5.50	5.25	5.50	5.25	5.25
Providing Essential Air Traffic Control Information	5.25	5.25	5.25	5.25	5.50	5.25	5.25	5.25
Providing Additional Air Traffic Control Information	5.00	5.00	5.00	5.50	5.00	5.25	5.25	5.00
Providing Coordination	5.25	5.25	5.00	5.50	5.50	5.25	5.50	5.00
Overall Providing Control Information Scale Rating	5.25	5.00	5.00	5.50	5.50	5.25	5.50	5.25
Showing Knowledge of LOAs and SOPs	5.25	5.50	5.25	5.50	5.50	5.75	5.25	5.25
Showing Knowledge of Aircraft Capabilities and Limitations	5.25	5.50	5.50	5.50	5.25	5.75	5.25	5.00
Showing Effective Use of Equipment	5.25	5.25	5.25	4.75	5.50	5.75	5.25	5.25
Overall Technical Knowledge Scale Rating	5.25	5.50	5.25	5.25	5.50	5.75	5.25	5.25
Using Prescribed Phraseology	5.25	5.50	5.00	5.50	5.50	5.50	5.50	5.50
Communicating Clearly and Efficiently	5.00	5.50	4.50	5.25	5.25	5.50	5.50	5.50

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Listening to Pilot Readbacks and Requests	5.25	5.50	5.25	5.50	5.25	5.75	5.50	5.50
Overall Communicating Scale Rating	5.25	5.50	5.00	5.50	5.25	5.50	5.50	5.50

Appendix M: Results – Configuration 2A, Sutro

Table M-1 Summary of Post-Scenario Questionnaire Data (Config 2A, Sutro)

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
NASA-TLX, Mental Demand	4.00	5.75	4.25	3.75	6.25	4.25	6.25	5.25
NASA-TLX, Physical Demand	4.00	5.50	3.75	3.75	6.00	4.00	5.75	4.50
NASA-TLX, Temporal Demand	3.50	5.25	4.25	3.75	6.25	4.25	6.00	4.50
NASA-TLX, Performance	6.75	6.50	6.50	6.75	5.50	6.75	6.00	6.25
NASA-TLX, Effort	4.00	5.75	4.25	4.00	6.25	4.50	5.00	4.50
NASA-TLX, Frustration	3.00	4.75	3.50	3.00	6.00	3.75	4.50	4.00
Overall effectiveness of sector management and services provided	7.00	6.00	7.00	7.00	5.67	6.33	6.67	7.33
Overall Safety	7.67	6.67	7.33	7.00	4.67	5.33	6.67	8.00
Overall Efficiency	7.00	6.00	7.67	6.67	5.67	4.67	6.33	7.00
Ability to identify and resolve aircraft conflicts safely	5.75	5.75	5.00	5.00	3.75	5.00	5.25	5.00
Ability to move aircraft efficiently through the sector	5.50	5.25	5.00	5.00	3.75	4.75	5.00	4.75
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	3.50	5.00	5.00	4.50	4.50	4.50	3.00
Overall Workload	4.00	5.75	4.75	3.50	5.25	4.25	5.50	4.25
Workload due to controller-to-pilot communications	3.75	4.50	4.25	2.75	3.75	3.50	5.00	4.50
Workload due to controller-to-front line manager communications	2.00	3.00	1.50	1.50	4.00	2.75	3.75	2.00

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.00	4.50	5.50	4.50	4.50	3.50	4.00
Overall level of SA	4.75	7.00	6.50	6.25	6.75	7.00	7.25	7.25
SA for detecting aircraft conflicts	5.25	7.25	7.00	7.50	6.00	7.25	7.50	7.50
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.50	5.00	5.00	4.00	5.00	4.50	5.00
Overall performance of the simulation pilots	7.50	8.00	8.00	8.25	7.50	8.75	8.00	8.25
Overall difficulty of the scenario	4.50	5.75	3.75	4.00	6.25	4.50	5.25	4.25

Table M-2 Summary of Safety & Efficiency Data (Config 2A, Sutro)

Safety & Efficiency	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
LOS	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
LOS-MVA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HFR	0.00	1.00	0.50	0.00	2.50	0.25	0.50	1.25
Departure Delay	0.00	2.75	0.00	0.00	3.75	1.25	2.00	3.75
Arrival Delay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table M-3 Summary of Time/Distance/Transmissions Data (Config 2A, Sutro)

Time/Distance/ Transmissions	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Flights	52	53	53	53	50	53	47	47
Flights-Total Time, Seconds	12,412	12,398	12,243	12,375	11,471	11,780	10,517	11,367
Flights-Mean Time, Seconds	237	233	232	235	229	222	224	242
Flights-Total Distance, NM	650	638	646	655	604	631	562	597

Time/Distance/ Transmissions	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Flights-Mean Distance, NM	12	12	12	12	12	12	12	13
PTTs	99	100	99	105	101	96	89	81
PTTs-Total Time, Seconds	362	346	352	372	346	356	313	304
PTTs-Mean Time, Seconds	4	3	4	4	3	4	4	4

Table M-4 Summary of WAK Data (Config 2A, Sutro)

WAK Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Interval #1, 00:00-04:00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.50
Interval #2, 04:00-08:00	1.67	1.33	1.33	2.00	1.67	2.33	1.33	1.33
Interval #3, 08:00-12:00	2.67	1.33	1.33	2.00	2.00	1.67	2.00	1.67
Interval #4, 12:00-16:00	3.00	1.00	1.00	2.00	2.00	2.00	2.50	1.50
Interval #5, 16:00-20:00	2.67	1.67	2.00	2.67	3.67	2.33	2.33	2.00
Interval #6, 20:00-24:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Interval #7, 24:00-28:00	2.00	2.50	1.50	2.00	3.00	2.00	1.50	2.50
Mean WAK Rating	2.42	1.36	1.29	2.14	2.39	2.04	1.86	1.79

Table M-5 Summary of Observer Ratings Data (Config 2A, Sutro)

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Maintaining Separation and Resolving Potential Conflicts	6.25	6.25	6.75	6.50	6.50	6.25	6.75	6.25
Sequencing Aircraft Efficiently	6.25	6.00	6.50	6.50	6.25	6.00	6.75	6.25

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Using Control Instructions Effectively/ Efficiently	6.25	6.00	6.75	6.25	5.75	6.00	6.50	6.25
Overall Safe and Efficient Traffic Flow Scale Rating	6.50	6.25	6.75	6.75	6.00	6.25	7.00	6.50
Maintaining Awareness of Aircraft Positions	6.00	6.50	7.00	6.50	6.25	6.25	6.75	6.25
Giving and Taking Handoffs in a Timely Manner	6.50	6.50	6.75	6.50	6.50	6.25	6.75	6.25
Ensuring Positive Control	6.00	6.25	6.75	6.50	6.00	6.00	6.75	6.25
Detecting Pilot Deviations from Control Instructions	6.00	6.00	6.75	6.50	6.50	6.00	6.75	6.25
Correcting Own Errors in a Timely Manner	6.25	6.50	6.75	6.50	6.25	5.75	6.75	6.25
Overall Attention and SA Scale Rating	6.00	6.50	7.00	6.75	6.50	6.25	7.00	6.50
Taking Actions in an Appropriate Order of Importance	6.50	6.25	6.50	6.50	6.00	6.00	6.25	6.25
Preplanning Control Actions	6.25	6.25	6.00	6.50	6.00	5.75	6.50	6.25
Handling Control Tasks for Several Aircraft	6.00	6.25	6.50	6.50	6.50	6.00	6.25	6.25
Marking Flight Progress Strips while Performing Other Tasks	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Overall Prioritizing Scale Rating	6.00	6.00	6.33	6.33	6.00	6.67	6.00	6.00
Providing Essential Air Traffic Control Information	6.25	6.25	6.50	6.50	6.25	6.00	6.25	6.25
Providing Additional Air Traffic Control Information	5.75	6.00	6.25	6.25	5.75	5.75	6.00	6.00
Providing Coordination	6.25	6.00	6.50	6.25	6.50	5.75	6.25	6.25
Overall Providing Control Information Scale Rating	6.00	6.00	6.33	6.00	6.00	6.33	6.00	6.00
Showing Knowledge of LOAs and SOPs	7.33	6.67	6.67	6.67	6.67	6.33	7.00	6.67
Showing Knowledge of Aircraft Capabilities and Limitations	6.75	6.50	6.50	6.25	6.00	6.00	6.25	6.50
Showing Effective Use of Equipment	6.50	5.75	6.50	6.25	6.25	6.00	6.25	6.50
Overall Technical Knowledge Scale Rating	7.00	6.50	6.75	6.50	6.25	6.25	6.50	6.75
Using Prescribed Phraseology	6.50	5.75	6.00	6.25	5.50	5.50	6.00	5.75
Communicating Clearly and Efficiently	6.25	6.25	6.25	6.25	6.25	5.50	6.00	6.25
Listening to Pilot Readbacks and Requests	6.25	6.00	6.00	6.25	6.00	5.75	6.00	6.50

Observer Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Overall Communicating Scale Rating	6.25	6.25	6.25	6.50	6.00	5.75	6.25	6.50

Appendix N: Results – Configuration 2A, Coordinator

Table N-1 Summary of Post-Scenario Questionnaire Data (Config 2A, CI)

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
NASA-TLX, Mental Demand	5.25	8.00	6.75	7.75	7.75	6.75	7.25	7.50
NASA-TLX, Physical Demand	4.75	6.75	5.75	5.75	6.50	4.00	5.75	6.25
NASA-TLX, Temporal Demand	5.50	7.00	5.50	6.25	6.75	5.75	6.75	7.25
NASA-TLX, Performance	8.00	8.00	7.50	5.50	5.25	6.50	6.50	6.00
NASA-TLX, Effort	5.25	6.75	5.75	6.50	7.50	6.25	6.75	7.25
NASA-TLX, Frustration	4.25	4.50	3.25	5.00	5.25	4.75	5.00	5.00
Overall effectiveness of sector management and services provided	7.33	8.00	6.67	5.33	4.67	6.00	6.33	6.00
Overall Safety	7.67	5.33	8.00	5.33	3.00	7.33	7.33	5.67
Overall Efficiency	7.00	5.33	7.67	5.00	5.00	7.00	7.00	6.33
Ability to identify and resolve aircraft conflicts safely	6.00	4.50	6.00	4.00	5.50	5.75	4.75	5.25
Ability to move aircraft efficiently through the sector	6.67	5.67	7.00	4.67	4.67	4.67	4.33	4.67
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	4.25	4.25	5.00	4.00	3.25	4.00	3.00
Overall Workload	5.50	8.25	6.25	7.50	7.75	6.25	6.75	8.00
Workload due to controller-to-pilot communications	7.50	6.00	6.50	7.50	8.00	4.50	7.50	7.50
Workload due to controller-to-front line manager communications	1.67	2.67	2.67	2.33	3.00	2.67	4.33	4.00

Post-Scenario Questionnaire	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.50	3.50	3.75	3.75	3.00	4.25	5.25
Overall level of SA	8.00	6.00	7.00	7.75	6.00	6.50	6.50	5.75
SA for detecting aircraft conflicts	7.00	5.33	6.00	8.00	5.67	5.67	5.67	5.33
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	5.00	5.50	5.50	5.75	5.25	5.50	5.25
Overall performance of the simulation pilots	7.00	6.00	8.00	7.67	6.33	8.00	6.67	8.00
Overall difficulty of the scenario	5.50	7.00	5.75	7.25	8.25	7.50	7.00	7.75

Table N-2 Summary of WAK Data (Config 2A, CI)

WAK Ratings	Baseline	Lost Link C	Lost Link D	Flight Term	Engine Failure	Lost Link M	Lost Comm	Fly-away
Interval #1, 00:00-04:00	1.50	1.25	2.00	1.75	1.50	1.50	1.50	1.25
Interval #2, 04:00-08:00	2.67	4.00	3.67	3.00	3.00	3.33	3.67	2.33
Interval #3, 08:00-12:00	3.67	4.67	4.00	3.33	2.67	4.33	3.67	2.67
Interval #4, 12:00-16:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Interval #5, 16:00-20:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Interval #6, 20:00-24:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Interval #7, 24:00-28:00	2.00	3.50	2.50	4.00	2.50	2.50	3.00	4.00
Mean WAK Rating	3.36	4.00	3.36	3.57	3.14	3.43	3.42	2.96

Appendix O: Results – Configuration 3, Mulford

Table O-1 Summary of Post-Scenario Questionnaire Data (Config 3, Mulford)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Divert
NASA-TLX, Mental Demand	5.83	6.08	6.50	6.25	7.33
NASA-TLX, Physical Demand	3.00	3.33	3.75	3.75	4.00
NASA-TLX, Temporal Demand	4.67	5.25	5.58	5.92	6.67
NASA-TLX, Performance	7.64	6.82	6.36	6.82	5.82
NASA-TLX, Effort	5.92	6.25	6.75	6.42	7.50
NASA-TLX, Frustration	3.83	3.83	4.50	4.58	5.17
Overall effectiveness of sector management and services provided	7.25	6.67	6.42	6.08	5.67
Overall Safety	8.08	6.92	7.08	6.17	5.83
Overall Efficiency	7.08	6.08	6.00	6.25	5.25
Ability to identify and resolve aircraft conflicts safely	5.09	4.45	4.82	4.55	3.36
Ability to move aircraft efficiently through the sector	5.18	4.18	4.55	4.27	3.36
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	3.91	4.00	3.91	3.91
Overall Workload	6.09	6.91	6.91	6.73	7.64
Workload due to controller-to-pilot communications	5.82	5.64	5.73	6.36	5.73
Workload due to controller-to-front line manager communications	1.50	3.70	4.10	3.50	3.60
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.00	4.00	3.70	3.90
Overall level of SA	7.75	7.25	6.92	6.58	6.50
SA for detecting aircraft conflicts	7.83	7.33	6.83	6.33	6.25
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	3.92	4.50	4.33	4.17
Overall performance of the simulation pilots	6.92	7.83	6.17	6.58	7.75
Overall difficulty of the scenario	5.75	6.75	6.50	6.17	7.83

Table O-2 Summary of Safety & Efficiency Data (Config 3, Mulford)

Safety & Efficiency	Baseline	Lost Link	Lost Comm	Fly-away	Divert
LOS	0.08	0.08	0.17	0.08	0.17
LOS-MVA	0.00	0.08	0.00	0.00	0.08
HFR	1.83	1.75	1.92	1.58	1.50
Departure Delay	1.83	1.75	1.92	1.75	1.50
Arrival Delay	0.17	0.08	0.08	0.08	1.75

Table O-3 Summary of Time/Distance/Transmissions Data (Config 3, Mulford)

Time/Distance/ Transmissions	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Flights	23.67	23.58	22.92	23.83	21.33
Flights-Total Time, Seconds	7,163.17	6,911.17	7,222.83	6,906.50	6,354.17
Flights-Mean Time, Seconds	302.58	293.17	315.95	290.66	298.34
Flights-Total Distance, NM	289.71	283.76	290.17	282.33	254.80
Flights-Mean Distance, NM	12.24	12.04	12.69	11.87	11.96
PTTs	122.64	123.45	119.82	126.91	114.55
PTTs-Total Time, Seconds	469.04	476.32	466.73	486.32	446.29
PTTs-Mean Time, Seconds	3.83	3.88	3.92	3.85	3.94

Table O-4 Summary of WAK Data (Config 3, Mulford)

WAK Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Interval #1, 00:00-04:00	1.27	1.36	1.73	1.45	1.36
Interval #2, 04:00-08:00	1.43	1.43	2.14	1.29	1.43
Interval #3, 08:00-12:00	2.22	2.44	2.67	2.11	2.11
Interval #4, 12:00-16:00	2.00	2.25	3.00	3.00	2.63
Interval #5, 16:00-20:00	2.11	2.67	2.44	2.67	3.00
Interval #6, 20:00-24:00	2.63	3.00	2.63	2.75	3.25
Interval #7, 24:00-28:00	2.13	1.88	1.88	2.25	2.88
Mean WAK Rating	1.95	2.13	2.33	2.17	2.32

Table O-5 Summary of Observer Ratings Data (Config 3, Mulford)

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Maintaining Separation and Resolving Potential Conflicts	5.08	5.58	6.00	5.25	5.33
Sequencing Aircraft Efficiently	5.50	5.75	5.83	5.50	5.50
Using Control Instructions Effectively/Efficiently	5.33	5.75	5.67	5.17	5.75
Overall Safe and Efficient Traffic Flow Scale Rating	5.33	5.75	5.75	5.33	5.50
Maintaining Awareness of Aircraft Positions	5.50	5.33	5.92	5.42	5.67
Giving and Taking Handoffs in a Timely Manner	5.83	5.58	5.83	5.67	5.67
Ensuring Positive Control	5.17	5.42	5.42	5.08	5.42
Detecting Pilot Deviations from Control Instructions	5.42	5.25	5.33	5.83	5.33
Correcting Own Errors in a Timely Manner	5.17	5.67	5.67	5.25	5.25
Overall Attention and SA Scale Rating	5.42	5.58	5.58	5.33	5.50
Taking Actions in an Appropriate Order of Importance	5.36	5.82	5.82	5.45	5.91
Preplanning Control Actions	5.55	5.73	5.82	4.73	5.55
Handling Control Tasks for Several Aircraft	5.55	5.64	5.82	5.27	5.73
Marking Flight Progress Strips while Performing Other Tasks	6.50	6.25	6.75	6.50	6.25
Overall Prioritizing Scale Rating	5.55	5.82	5.82	5.09	5.55
Providing Essential Air Traffic Control Information	5.64	5.73	5.91	5.09	5.27
Providing Additional Air Traffic Control Information	5.27	5.27	5.45	4.55	5.18
Providing Coordination	5.64	5.64	6.00	4.91	5.27
Overall Providing Control Information Scale Rating	5.55	5.73	5.91	4.82	5.27
Showing Knowledge of LOAs and SOPs	5.75	5.50	5.75	4.75	5.67

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Showing Knowledge of Aircraft Capabilities and Limitations	5.67	5.25	5.00	4.83	5.50
Showing Effective Use of Equipment	5.75	5.42	5.67	5.50	5.58
Overall Technical Knowledge Scale Rating	5.75	5.50	5.50	5.00	5.50
Using Prescribed Phraseology	5.42	5.75	5.58	4.83	5.33
Communicating Clearly and Efficiently	5.17	5.25	5.33	4.33	4.92
Listening to Pilot Readbacks and Requests	5.50	5.42	5.67	5.00	5.08
Overall Communicating Scale Rating	5.33	5.50	5.50	4.67	5.25

Appendix P: Results – Configuration 3, Grove

Table P-1 Summary of Post-Scenario Questionnaire Data (Config 3, Grove)

Post-Scenario Questionnaire	Baseline	Lost Link	Lost Comm	Fly-away	Divert
NASA-TLX, Mental Demand	3.83	4.67	4.00	4.00	6.83
NASA-TLX, Physical Demand	2.67	2.50	2.33	2.25	4.00
NASA-TLX, Temporal Demand	3.08	3.50	3.50	3.08	6.67
NASA-TLX, Performance	8.08	7.33	8.00	7.58	7.00
NASA-TLX, Effort	4.33	5.33	4.25	4.33	7.33
NASA-TLX, Frustration	2.83	3.17	2.25	2.92	5.33
Overall effectiveness of sector management and services provided	7.00	7.33	7.17	7.08	6.17
Overall Safety	8.08	7.92	8.00	7.75	6.67
Overall Efficiency	7.58	7.58	7.67	7.67	5.67
Ability to identify and resolve aircraft conflicts safely	5.27	5.09	5.09	5.18	4.00
Ability to move aircraft efficiently through the sector	4.91	4.73	5.00	5.09	3.27
Effect UAS operations had on sector management, and services provided (If no UAS, response is N/A)	N/A	4.50	4.70	4.60	4.50
Overall Workload	4.42	5.08	5.08	4.50	7.92
Workload due to controller-to-pilot communications	4.75	4.00	3.83	3.83	6.83
Workload due to controller-to-front line manager communications	1.10	1.60	1.50	1.20	1.60
Effect UAS operations had on overall workload (If no UAS, response is N/A)	N/A	4.45	4.45	4.18	4.55
Overall level of SA	8.00	6.82	7.55	7.36	7.36
SA for detecting aircraft conflicts	8.00	7.09	7.36	7.36	7.09
Effect UAS operations had on your overall SA (If no UAS, response is N/A)	N/A	4.60	4.80	5.00	4.40
Overall performance of the simulation pilots	7.75	7.92	8.25	8.25	7.58
Overall difficulty of the scenario	4.18	4.64	5.00	4.00	7.45

Table P-2 Summary of Safety & Efficiency Data (Config 3, Grove)

Safety & Efficiency	Baseline	Lost Link	Lost Comm	Fly-away	Divert
LOS	0.00	0.00	0.08	0.08	0.08
LOS-MVA	0.00	0.00	0.00	0.00	0.00
HFR	0.17	0.25	0.33	0.33	0.08
Departure Delay	0.17	0.25	0.33	0.33	0.08
Arrival Delay	0.00	0.00	0.08	0.00	0.33

Table P-3 Summary of Time/Distance/Transmissions Data (Config 3, Grove)

Time/Distance/ Transmissions	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Flights	37.92	38.50	38.08	37.42	37.50
Flights-Total Time, Seconds	12,952.42	13,886.17	13,511.50	12,471.33	14,126.67
Flights-Mean Time, Seconds	341.50	361.03	354.72	333.54	376.78
Flights-Total Distance, NM	500.87	537.53	527.27	487.64	565.44
Flights-Mean Distance, NM	13.21	13.98	13.84	13.05	15.08
PTTs	78.64	77.09	74.64	72.27	94.00
PTTs-Total Time, Seconds	323.69	325.37	318.40	300.74	386.32
PTTs-Mean Time, Seconds	4.12	4.22	4.28	4.17	4.11

Table P-4 Summary of WAK Data (Config 3, Grove)

WAK Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Interval #1, 00:00-04:00	1.27	1.27	1.27	1.18	1.36
Interval #2, 04:00-08:00	1.40	1.70	1.30	1.40	1.50
Interval #3, 08:00-12:00	1.67	1.89	1.78	1.56	1.56
Interval #4, 12:00-16:00	1.33	1.50	1.67	1.17	1.67
Interval #5, 16:00-20:00	1.89	2.33	1.89	1.89	2.56
Interval #6, 20:00-24:00	1.89	1.89	1.89	1.67	3.22
Interval #7, 24:00-28:00	1.33	1.33	1.11	1.33	3.11

WAK Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Mean WAK Rating	1.47	1.67	1.52	1.35	2.13

Table P-5 Summary of Observer Ratings Data (Config 3, Grove)

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Maintaining Separation and Resolving Potential Conflicts	6.00	5.83	6.08	5.92	5.75
Sequencing Aircraft Efficiently	6.08	6.00	6.08	5.83	5.83
Using Control Instructions Effectively/Efficiently	5.83	5.92	6.00	5.75	5.58
Overall Safe and Efficient Traffic Flow Scale Rating	6.00	5.92	6.17	5.92	5.75
Maintaining Awareness of Aircraft Positions	6.00	6.08	6.08	6.17	5.58
Giving and Taking Handoffs in a Timely Manner	6.00	5.92	5.92	6.08	5.33
Ensuring Positive Control	5.92	5.75	5.83	5.67	5.58
Detecting Pilot Deviations from Control Instructions	6.17	5.67	6.00	5.67	5.83
Correcting Own Errors in a Timely Manner	6.17	5.83	6.00	5.75	5.67
Overall Attention and SA Scale Rating	6.08	5.83	6.00	5.92	5.50
Taking Actions in an Appropriate Order of Importance	5.92	6.00	6.08	6.08	5.83
Preplanning Control Actions	5.67	5.75	6.33	5.83	5.75
Handling Control Tasks for Several Aircraft	6.08	5.83	6.00	5.92	5.92
Marking Flight Progress Strips while Performing Other Tasks	5.33	6.00	5.67	6.00	6.00
Overall Prioritizing Scale Rating	5.60	5.80	6.00	5.80	5.90
Providing Essential Air Traffic Control Information	5.92	6.00	5.92	6.08	5.92
Providing Additional Air Traffic Control Information	5.58	5.67	5.83	5.83	5.17
Providing Coordination	5.92	5.67	6.17	5.75	5.25

Observer Ratings	Baseline	Lost Link	Lost Comm	Fly-away	Divert
Overall Providing Control Information Scale Rating	5.92	5.67	5.92	6.17	5.42
Showing Knowledge of LOAs and SOPs	6.09	6.00	6.18	6.00	5.91
Showing Knowledge of Aircraft Capabilities and Limitations	5.91	5.91	6.18	6.27	6.00
Showing Effective Use of Equipment	6.09	6.09	5.82	6.27	5.91
Overall Technical Knowledge Scale Rating	6.00	6.09	6.18	6.36	6.00
Using Prescribed Phraseology	5.75	5.67	5.83	5.92	5.75
Communicating Clearly and Efficiently	5.50	5.50	5.83	5.58	5.17
Listening to Pilot Readbacks and Requests	5.83	5.75	5.92	5.67	4.58
Overall Communicating Scale Rating	5.58	5.58	5.92	5.75	4.92

Appendix Q: Results – UAS with No Contingency Event

As stated in Section 7, in-depth analysis of "non-event" UAS operations was outside the scope of this research by design and therefore all UAS scenarios included a planned contingency. For the objectives of this study, the assumption was made that that there would be no operational difference between the baseline runs used (all of which include only manned aircraft), and a set of baseline runs including UAS that did not experience any abnormal operations. However, it is fully recognized that abnormal events do occur, and improved understanding and methods to mitigate the impact of UAS contingency operations is needed to achieve full acceptance for integration.

To support the baseline assumption of the study, analyses of the "non-event" periods of operations were conducted. While the sampling of these "non-event" periods of UAS operations used smaller time periods than those used for UAS contingency operations, they suggest that "non-event" UAS operations in the NAS would not have significant impacts on system safety, efficiency, or controller workload, as expected.

The data was sampled from the time periods from each contingency scenario in which the UAS was operating prior to experiencing the contingency event. Hence, the comparison is made between non-event UAS operations ("normal") to the baseline condition in which there was no UAS. For example, in Figure Q-1, the number of arrival delays, departure delays, and HFRs were tallied for the baseline and the lost link scenarios between the time periods of 06:00-13:00. The UAS entered the scenario at the 06:00-minute mark, and the lost-link event occurred around the 13:00-minute mark.

The results from all three configurations are shown in Figure Q-1 through Figure Q-5 from an efficiency and workload perspective. Safety results are not shown, as safety was shown to have no significant effect overall, regardless of the presence of a UAS contingency event.

In Configuration 1, the UAS entered the airspace at ~06:00 and the lost link occurred ~13:00. The WAK ratings for the Grove HO position, from 00:00-12:00, are provided as an estimate of the workload experienced under normal UAS operations.

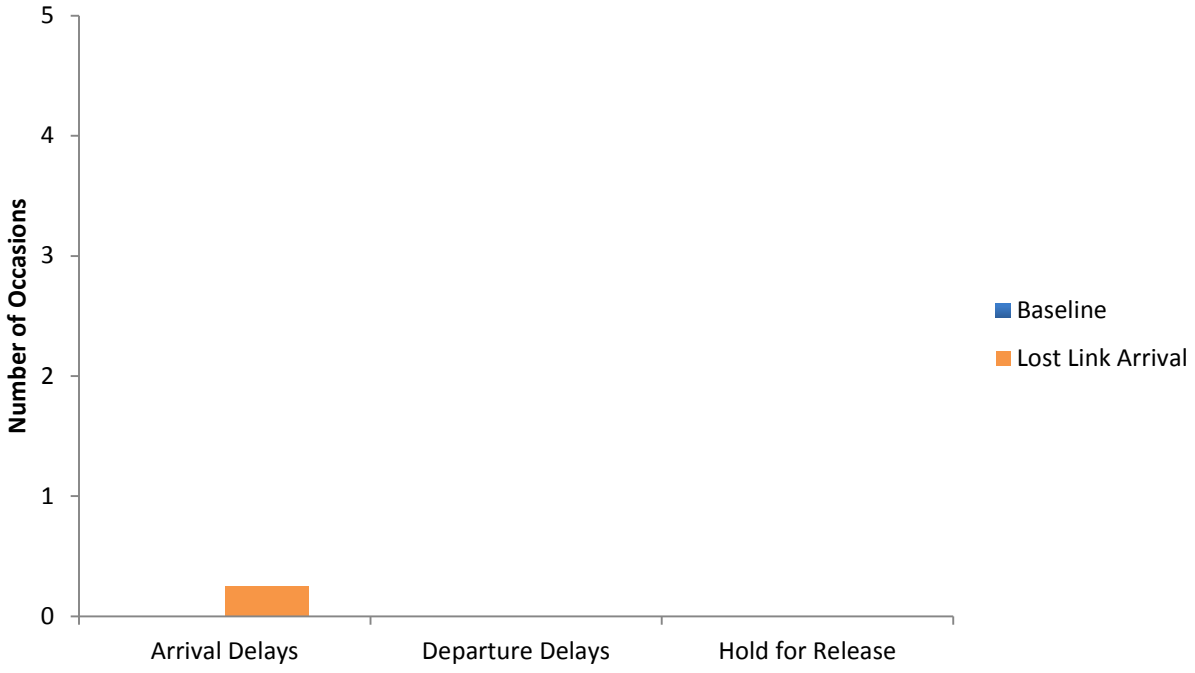

Figure Q-1 Efficiency Measures for 06:00-13:00, Configuration 1

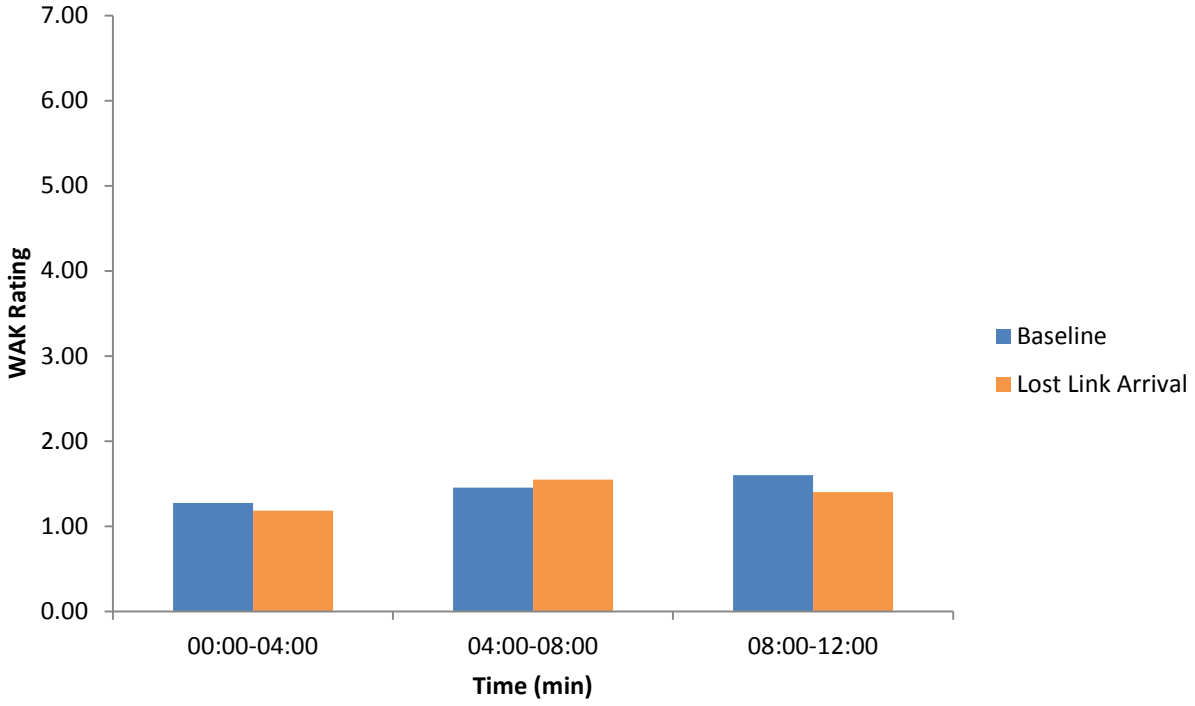

Figure Q-2 WAK Ratings, Configuration 1

In Configuration 2A, the UAS entered the airspace at 00:00 and the first of the UAS lost-link events occur at ~10:00. In this scenario, there were actually two UAs in the airspace for some duration of time before the event occurred. There were no arrival delays, no departure delays, and no HFRs initiated during this time period. The WAK ratings for both Richmond and Sutro positions, from 00:00-08:00, are provided as an estimate of the workload experienced under normal UAS operations.

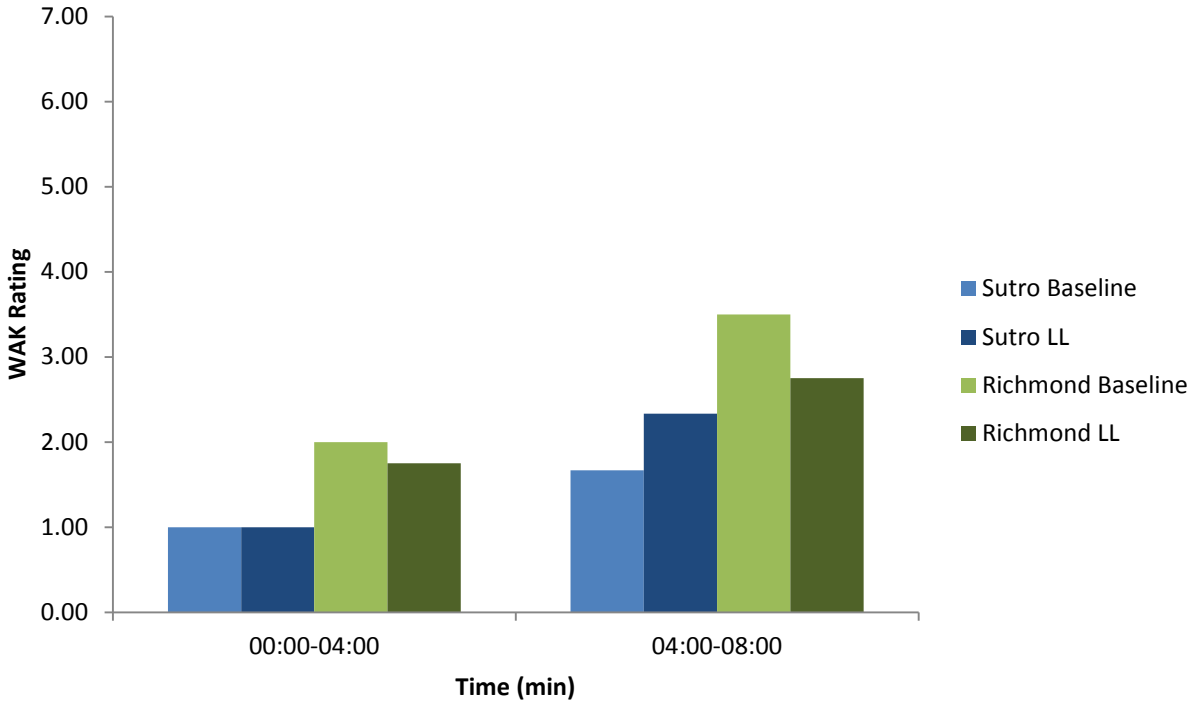

Figure Q-3 WAK Ratings, Configuration 2A

In Configuration 3, the UA entered the airspace at ~06:00 and the fly-away event occurred at ~13:00. The efficiency counts are provided in Figure Q-4, and Figure Q-5 shows the WAK ratings from 00:00-12:00 as an estimate of the workload experienced under normal UAS operations.

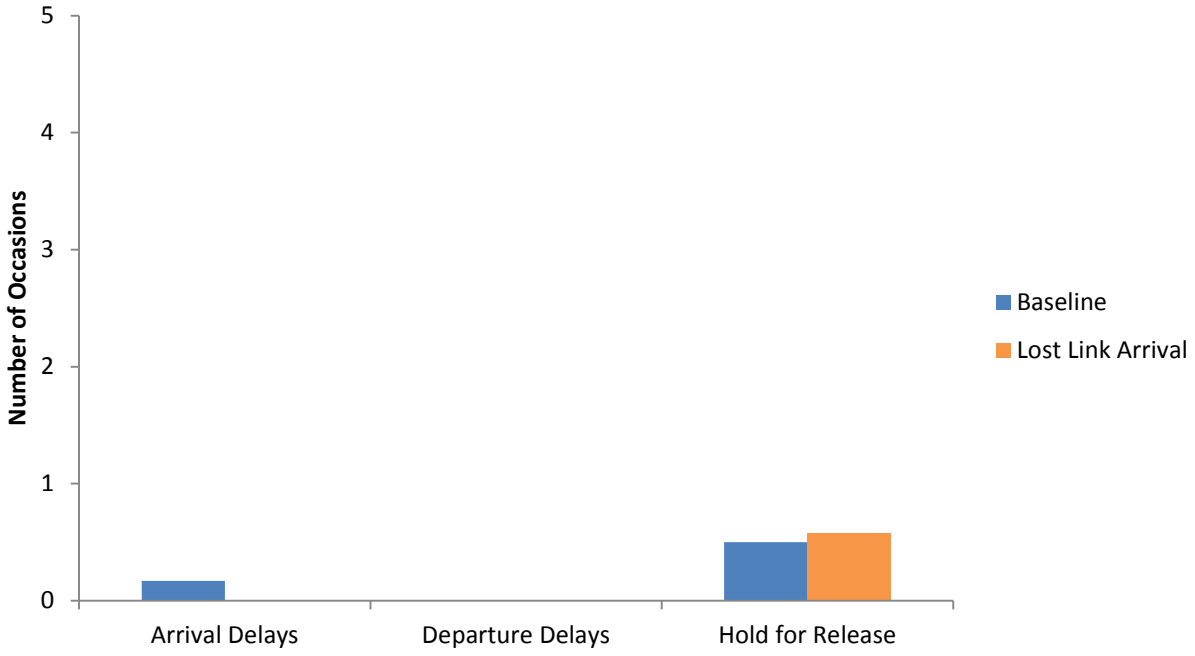

Figure Q-4 Efficiency Measures for 06:00-13:00, Configuration 3

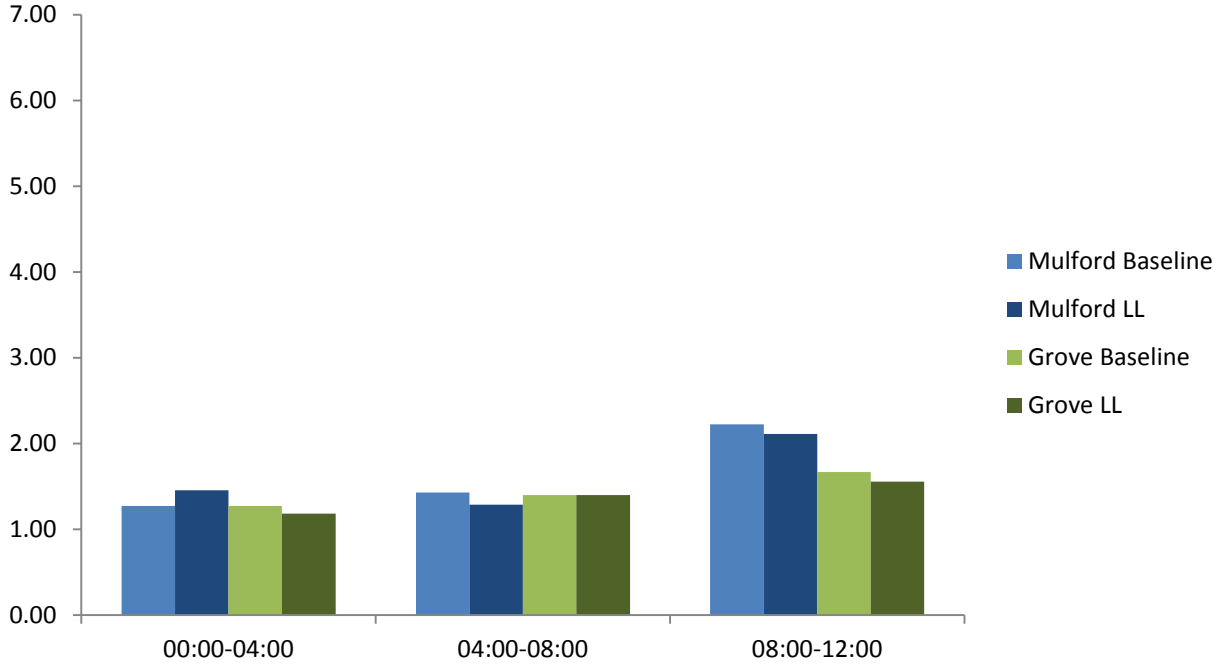

Figure Q-5 WAK Ratings (1-7), Configuration 3

This page intentionally left blank.