NASA/TP–2013-218007

Flight Crew Workload, Acceptability, and Performance When Using Data Comm in a High-Density Terminal Area Simulation

R. Michael Norman
Boeing Research and Technology, Hampton, Virginia

Brian T. Baxley, Catherine A. Adams, Kyle K. E. Ellis,
Kara A. Latorella, and James R. Comstock, Jr.
Langley Research Center, Hampton, Virginia

June 2013

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to help@sti.nasa.gov

- Fax your question to the NASA STI Information Desk at 443-757-5803

- Phone the NASA STI Information Desk at 443-757-5802

- Write to:
  STI Information Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TP–2013-218007

Flight Crew Workload, Acceptability, and Performance When Using Data Comm in a High-Density Terminal Area Simulation

R. Michael Norman
Boeing Research and Technology, Hampton, Virginia

Brian T. Baxley, Cathy A. Adams, Kyle K. E. Ellis,
Kara A. Latorella, and James R. Comstock, Jr.
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

June 2013

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

Foreword

This NASA Technical Paper is a refinement of a report provided on 28 July 2010 to Mr. Levent Ileri, of the FAA Data Comm Program office, titled *"NASA / FAA Data Comm Airside Human-in-the-Loop Simulation."* That document served as the Final Report specified in the FAA/NASA Interagency Agreement IA1-973, Technical Direction 1, Paragraph 1.1.10 (FAA Agreement DTFAWA-09-A-80018). Generally FAA documents are not publically accessible, therefore with concurrence from both FAA and NASA, this document republishes that information as a NASA TP with administrative corrections and some formatting changes. No data was added or changed, however typographical errors were corrected, clarifying text and figures were added, and in a few instances different analysis was performed.

The authors thank Mr. Ileri and the FAA Data Comm Program for the opportunity to conduct this challenging human-in-the-loop simulation at NASA Langley Research Center.

The authors also express sincere thanks and gratitude to the many implementation team members in the D-107 Simulation Development and Analysis Branch at NASA Langley Research Center that we worked with on a daily basis for a year. In particular, Paul Sugden wrote specialized software necessary to conduct this experiment and Jerry Karwac created the graphical displays that were key to this work. Others from D-107 that contributed significantly over many hours include Tom Feigh, Dennis Frasca, Chris Harrison, Sonia Herndon, Brian Hutchinson, Kemper Kibler, Wendy Pifer, Cassie Ruddiman, Darrel Sacra, Phil Smith, Joe Whiting, and Brittany Williams. Individuals from other Branches the authors wish to thank include William Lynn and Dan Burdette who made important contributions to the work required to install and use the oculometer system, and Regina Johns who did an incredible job recruiting subject pilots, as well as arranging their travel and accommodations.

Table of Contents

List of Figures

List of Tables

Abbreviations

ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance - Broadcast
AHP	Analytical Hierarchy Process
ANOVA	Analysis of Variance
ANSP	Air Navigation Service Provider
APU	Auxiliary Power Unit
A-SMGCS	Advanced-Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATO	Air Traffic Organization
CDTI	Cockpit Display of Traffic Information
CDU	Control Display Unit
CPDLC	Controller Pilot Data Link Communications
CRM	Crew Resource Management
D-ATIS	Digital ATIS
D-TAXI	Data link Taxi instructions
DC	Data Communications / Data Comm
DM	Downlink Message
EFIS	Electronic Flight Instrumentation System
EICAS	Engine Indicating and Crew Alerting System
EMMA	European Airport Movement Management by A-SMGCS
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FANS-1/A	Future Air Navigation System 1/A
FMS	Flight Management System
HITL	Human-In-The-Loop
HSD	Honestly Significant Difference
IFD	Integration Flight Deck
ILS	Instrument Landing System
KBOS	Boston Logan International Airport
KIAS	Knots Indicated Air Speed
LaRC	NASA Langley Research Center (Hampton, VA)
MMD	Moving Map Display

MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NextGen	Next Generation Air Transportation System
NLR	National Aerospace Laboratory of the Netherlands
NWS	Nose Wheel Steering
OTW	Out-The-Window
PF	Pilot Flying (Captain in this experiment)
PFD	Primary Flight Display
PM	Pilot Monitoring (First Officer in this experiment)
PSD	Power Spectral Density
RDHFL	Research Development and Human Factors Laboratory
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TCAS	Traffic alert and Collision Avoidance System
UM	Uplink Message
VMC	Visual Meteorological Conditions
WJHTC	William J. Hughes Technical Center (Atlantic City, NJ)

Abstract

This document describes a collaborative FAA/NASA experiment using 22 commercial airline pilots to determine the effect of using Data Comm to issue messages during busy, terminal area operations. Four conditions were defined that span current day to future flight deck equipage: Voice communication only, Data Comm only, Data Comm with Moving Map Display, and Data Comm with Moving Map displaying taxi route. Each condition was used in an arrival and a departure scenario at Boston Logan Airport. Of particular interest was the flight crew response to D-TAXI, the use of Data Comm by Air Traffic Control (ATC) to send taxi instructions. Quantitative data was collected on subject reaction time, flight technical error, operational errors, and eye tracking information. Questionnaires collected subjective feedback on workload, situation awareness, and acceptability to the flight crew for using Data Comm in a busy terminal area. Results showed that 95% of the Data Comm messages were responded to by the flight crew within one minute and 97% of the messages within two minutes. However, post experiment debrief comments revealed almost unanimous consensus that two minutes was a reasonable expectation for crew response. Flight crews reported that Expected D-TAXI messages were useful, and employment of these messages acceptable at all altitude bands evaluated during arrival scenarios. Results also indicate that the use of Data Comm for all evaluated message types in the terminal area was acceptable during surface operations, and during arrivals at any altitude above the Final Approach Fix, in terms of response time, workload, situation awareness, and flight technical performance. The flight crew reported the use of Data Comm as implemented in this experiment as unacceptable in two instances: in clearances to cross an active runway, and D-TAXI messages between the Final Approach Fix and 80 knots during landing roll. Critical cockpit tasks and the urgency of out-the-window scan made the additional head down time to respond to Data Comm messages undesirable during these events. However, most crews also stated that Data Comm messages without an accompanying audio chime and no expectation of an immediate response could be acceptable even during these events.

1 Introduction

In the fall of 2008, the FAA Air Traffic Organization (ATO) Operations Planning, Air Traffic Systems Concept Development and Validation Group, prepared a document outlining research needs for implementing data communications (Data Comm) in the Next Generation Air Transportation System (NextGen) as it related to the flight crew in the aircraft. In particular, NASA Langley Research Center was to provide an analysis of the impact caused by Data Comm on the flight crew in a human-in-the-loop (HITL) simulation that aligned with the FAA William J. Hughes Technical Center's (WJHTC) Research Development and Human Factors Laboratory (RDHFL) simulation studying the impact of Data Comm on controllers. The FAA referred to this Langley experiment as the *FAA/NASA Data Comm Airside Human-in-the-Loop Simulation*. An excerpt from Paragraph 3 of the research request document states:

> "The purpose of the airside research is to study Data Comm functionality and to determine how it can contribute to the ultimate NextGen goal of increased flight deck efficiency and capacity. To ensure that Data Comm successfully provides a digitally automated data communication system to support NextGen, the ATO Air Traffic Systems and Validation Group developed a Research Management Plan for Segment Two (FAA, 2008) that outlines a series of research initiatives and studies. These research initiatives and studies include cognitive walkthroughs, information flow models, part-task research studies, and high-fidelity HITL simulations of future operational concepts. The research efforts are pursued to help validate proposed Data Comm concepts and identify requirements that will be the basis for constructing the future air (and ground) Data Comm systems." [1]

The request was codified in the FAA/NASA Interagency Agreement IA1-973, Technical Direction 1, and a NASA Langley Research Center document was submitted to the FAA Data Comm Program as the Final Report specified in Paragraph 1.1.10 of that document. [2] This document was titled "NASA/FAA Data Comm Airside Human-in-the-Loop Simulation," and delivered on 28 July 2010. Key details and assumptions contained within that agreement and an Addendum are described in Appendix A. Additional requests for data analysis by the FAA after the experiment began have been accommodated in this report (*e.g.*, message response time by message type, reformat of results for Special Committee 214 (SC-214), etc.).

The primary objective of the experiment was to determine the acceptability of Data Comm to the flight crew during high traffic density operations in a complex terminal area with an operational environment appropriate to the FAA's Segment 2 timeframe (2017-2022). Of particular interest to the FAA was D-TAXI, or the use of Data Comm messages to send taxi routes to the flight crew. Acceptability was assessed in the context of expected, actual, and amended D-TAXI clearances during surface operations and while on approach, as well as other Data Comm messages (frequency change, altimeter setting, etc) throughout the scenarios. Three types of D-TAXI messages sent via Data Comm were used in this HITL experiment:

1. Expected D-TAXI: informative; for flight crew planning only (not used in today's operation)
2. D-TAXI: directive; taxi route assigned by ATC to flight crew (unlike today's operation, it does not include clearance to begin moving the aircraft)
3. Amended D-TAXI: directive; change to existing taxi route by ATC (the same as changing the taxi route in today's operation)

Specific planning regarding the objective, scope, experimental design, scenario definitions, and assumptions for the experiment was based on the requirements of that IA1-973 agreement, refined by the literature search, and subsequent interagency communication. [2] Joint Planning and Development Office and FAA documents were used to define expected operations and Data Comm capabilities for that timeframe. [3][4][5] A paper by the FAA ATO Data Comm Human Factors Working Group (HFWG-08) identified that guidance must be defined on when not to send messages so crew distractions during critical phases of flight are minimized. [6] The paper further listed a range of research needs to be conducted, that included identifying the impact of mixed modes of communication (using both Voice and Data Comm) on controllers and pilots, what is the acceptable delay in responding to Data Comm messages, and what is the impact of aural cues. Further, a white paper from the FAA Human Factors Research and Engineering Group (AJP-61) identified specific research needs for Data Comm in the Segment 2 time frame (2017-2022). In particular, it asked what Data Comm procedures should be, and are there cases and places in which Data Comm use should be avoided. [7]

2 Data Comm Literature Review

There has been considerable research conducted in the United States and Europe regarding the use of Data Comm messages between pilots and controllers, the impact it has on the flight crew's workload and scan pattern, when it should or should not be used, and what characteristics are needed for it to be considered acceptable by the crew. This section outlines Data Comm findings by topic (with the relevant studies mentioned in the appropriate paragraphs), then describes the impact of the literature review on the experiment design in the final paragraph.

2.1 When to use Voice or Data Comm

The LINK2000+ Flight Crew Datalink Operational Guide specifies how Controller Pilot Data Link Communication (CPDLC) will be used for routine, non time-critical instructions and requests while in the European en-route environment. It also defined the response time required between ground and airborne equipment, as well as between controller and flight crew. These guidelines were based on a human-in-the-loop simulation using controllers and pilots in European enroute airspace. Operational review of the experiment led to the requirement that Voice be used for all time-critical and safety-related communication. Other findings include delay in communication response, lack of flexibility in composing Data Comm messages, and loss of situation awareness (SA) when not using party line communication (such as Voice). [8][9]

Over 900 revenue flights at the Brussels airport from August 2006 through February 2007 participated in D-TAXI operational trials exploring procedures to improve productivity and safety while using non-time-critical messages for a medium to high taxi path complexity. Push-back, start-up, and taxi CPDLC messages were sent by ATC and responded to by the crew using CPDLC, however for operational and safety reasons, the crews also responded using Voice communication. Overall, pilot acceptance based on debrief comments was high and continued to increase as the experiment continued. Open issues from this research include: many of the crews did not respond to survey questions, existing equipage and procedures were used which were not optimized for a high-workload terminal area operations, and it was not clear what impact Data Comm caused to head up time or workload. [10]

2.2 Prioritization of Voice and Data Comm

Researchers from 24 multi-national partners (including air navigation service providers, airport operators, airlines, airframe, avionics, pilots, controllers, and research agencies) conducted a test called EMMA in 2004-2006, and EMMA2 in 2006-2009. EMMA (European Airport Movement Management by A-SMGCS) consolidated surveillance and conflict alert function for the controller, and EMMA2 focused on advanced onboard guidance support to pilots and planning support for controllers (A-SMGCS is the Advanced Surface Movement Guidance and Control System conducted in Europe). Multiple simulation platforms and operational test locations were used to explore the holistic, integrated air-ground system. For the taxi tests in Prague, Milan and Toulouse, the flight crew had a moving map display as well as surface alerts for other traffic and runway incursions and CPDLC was used to transmit taxi instructions. Requirements and safety analysis conducted by the consortium resulted in the requirement that Voice communication always took precedence over Data Comm, and was reported as a key result. EMMA results indicated taxi time and Voice communication were reduced, while EMMA2 concluded that CPDLC for taxi operations under these conditions was technically and operationally feasible. No oculometer or other measure of head up time data were collected to independently and quantitatively measure these effects (and implicitly, quantify pilot workload and situation awareness). [11][12][13][14][15] (NOTE: this influenced the decision to include oculometers.)

A 2008 report about the operational use of Data Comm in Maastricht airspace states the use of CPDLC is continuing to grow at a steady pace, with controllers initiating communication (uplink) more than 70 times for every time pilots initiate communication (downlink). The messages are for routine, strategic situations and supplement Voice commands, and Voice instruction take precedence over Data Comm. Although the primary response to a message should be in the same mode it was received in, Voice will be used to resolve complex, safety, and time-critical issues, or resolve any confusion between the controller and pilot. [16]

2. 3 Use of Data Comm Reduces Need for Voice Communication

NASA flight tests conducted at Denver's Stapleton Airport in the late 1980s using 9 pilots flying a total of 54 scenarios (each scenario a 60 nautical mile long arrival procedure) concluded that Data Comm greatly reduced voice congestion and had lower pilot workload. [17]

Research by Wright State and the FAA's William J Hughes Technical Center used eight pilots to explore the effects of CPDLC messages on controllers and pilots. While controller-pilot communication was decreased when using Data Comm, the amount of inter-crew communication was increased. The report further postulated that the increased discussion between pilots that occurs when using Data Comm communication may improve problem-solving and decision making within the cockpit. [18]

A conclusion from the LINK2000+ Real-Time Simulation Project was the benefit of a reduction in voice congestion. [9]

Another finding from the EMMA2 operational taxi trials in Europe found using CPDLC messages during taxi operations reduced the use of Voice communication by both controllers and flight crew. [13][14]

A report by Eurocontrol states the operational use of Data Comm within the Maastricht airspace has contributed to an increase in the safety of flight operations, as well as a reduction in controller-pilot voice communication congestion. [16]

2.4 Data Comm Acceptability

One of the early flight tests to explore the issue of Data Comm and flight crew interaction occurred in 1991. NASA Langley used a Boeing 737 and seven crews flying in both enroute and terminal area environments, with scenarios using either Voice or Data Comm as the primary controller to pilot link. The flight test showed a reduction in workload and greater pilot acceptability when the ability to "auto-load" the ATC instruction into the Flight Management System (FMS) was available. [19][20]

The National Aerospace Laboratory of the Netherlands (NLR) conducted research involving nine crews flying six gate-to-gate scenarios between London and Amsterdam. They identified that the ability to "auto-load" the Data Comm text message into the FMS substantially improved the crews rating of whether Data Comm was acceptable as a form of communication. Improvements in location (into the forward field of view on the center console) and the ability to "auto-load" information raised the acceptability rating from 56% to 94%. This research also concluded that the Control Display Unit (CDU) was the optimum Data Comm interface. [21]

Research from a Human Factors study at the FAA William J Hughes Technical Center (FAA WJHTC) recommended that Data Comm reception and interface devices be in the forward field of view, and that a distinct aural alert should be used to indicate the presence of Air Traffic Control (ATC) messages. [22]

NASA research titled "The Human Factors of FMS Usage in the Terminal Area" had ten two-person crews fly a Boeing 747-400 simulator into the Dallas Ft-Worth terminal area, using manual, auto-pilot, or FMS coupled to auto-pilot operations. The results concluded that while use of the FMS is acceptable in the terminal area, the use of the FMS resulted in the highest workload and lowest pilot satisfaction as reported by the pilots. [23]

2.5 Understanding Communication

The D-TAXI operational trials at Brussels from August 2006 through February 2007 used push-back, start-up, and taxi CPDLC messages sent from ATC, while the crew responded via CPDLC and Voice. Results suggest the flight crew found that the messages were easy to understand and there were no incidents or errors. [10]

The general conclusion from the LINK2000+ Real-Time Simulation Project was that all controllers found Data Comm acceptable, easy to use, and assisted in increasing safety. They also stated it was beneficial to have Data Comm available as a second communication channel for routine messages. [9]

NASA flight tests conducted at Denver's Stapleton Airport concluded that Data Comm was more accurate than Voice and lowered pilot workload. Cockpit equipage included the ability to automatically load the ATC instruction from the CDU into the FMS. [17]

The 1991 flight test by NASA Langley with a Boeing 737 and seven crews showed a reduction in confusion, errors, and need for message repetition when the ability to "auto-load" the ATC instruction into the FMS was available. [19][20]

A 2009 FAA study interviewed 48 pilots from various US airlines, and concluded Voice communication from non-native English speakers presents challenges to controllers and pilots on the receiving end of that transmission. In order to understand these challenges, a range of issues were identified to include pronunciation, syllable parsing, rate and timing of speech, and differences between ICAO and standard US phraseology. The study postulates employing Data Comm should significantly alleviate many of these problems. [24]

A NASA simulation study called "Integrating Datalink and Cockpit Display Technologies into Current and Future Taxi Operations" was conducted in 2002. Messages sent via Data Comm were found to reduce time spent writing clearances and improved the crews' ability to understand the message on the first attempt. [25]

A single pilot, general aviation study examined the effectiveness of three different Data Comm interfaces, involving voice, visual, and redundant presentation of the ATC information. Oculometers were also used to measure pilot scan patterns and dwell time. Eighteen pilots flew multiple scenarios and responded to several ATC instructions while scanning outside for traffic. Results revealed that the visual display of ATC instructions (Data Comm) provided the greatest accuracy of communications read back, was less disruptive, and resulted in the least flight technical error (deviation from flight path). The auditory-only condition was the most disruptive of the conditions, with the redundant display condition providing many of the same benefits as visual-only, but never better than visual only. [26]

2.6 Flight Crew Response Time

The LINK2000+ Real-Time Simulation Project found that the response of the flight crew in responding to controllers was delayed when using CPDLC as compared to Voice communications. This study, conducted in European enroute airspace, did not include cockpit displays to assist in understanding text clearances; nevertheless, the overwhelming majority (> 95%) of the flight crew responses occurred within 60 seconds. [9]

The D-TAXI revenue flights at Brussels using CPDLC for push-back and taxi operations reported high pilot acceptance; response time was longer although it was stated that it was not operationally significant. [10]

The NASA "Integrating Datalink and Cockpit Display" simulation examined the impact on flight crew of using Voice or Data Comm in three different modes: Voice only, Data Comm with Voice, and Data Comm without Voice. Flight crews took the longest to respond to communications and instructions in the Data Comm without Voice mode. However, the benefit of Data Comm may extend to increased operational efficiency, increased communication efficiency, and reduced radio congestion. [25]

Another NASA experiment evaluated flight deck procedures for Data Comm trajectory negotiations during cruise flight, and measured flight crew response time to the uplink messages as well as workload and acceptability. Results indicated workload did not have a significant impact on response times, response times were generally well within two minutes, and the procedures were deemed feasible. [27]

2.7 Flight Crew Head Up Time

The D-TAXI revenue flights at Brussels using CPDLC for push-back and taxi operations reported high pilot acceptance; however, head up time was decreased although it was stated that it was not an operationally significant factor. This result is based on pilot self-assessment during debrief, no independent measure was used. [10]

Research sponsored by the FAA and conducted by NLR in the mid 1990s used 18 American and European crews flying a simulator into Schiphol Airport, and determined that Data Comm uplink messages decreased the head up time of both crew members. Another finding was "… the fact that uplinks had an effect on the scanning behavior of the crew member not responsible for the communication task." The research stated the Pilot Flying (PF) had less head up time when Data Comm was being used due to interest in the message being received. [27]

2.8 Cockpit Graphical Displays

Research using 18 flight crews in a flight simulator by the FAA and NLR also reported the addition of a Traffic alert and Collision Avoidance System(TCAS) or Cockpit Display of Traffic Information (CDTI) would help maintain the awareness of the crew and offset the loss of Voice "party-line" information. [27]

The LINK2000+ Real-Time Simulation Project used controllers and pilots in European enroute airspace, and consisted of CPDLC Uplink and Downlink messages, to include heading and altitude changes, and frequency changes to the next controller. One issue identified was the flight crew's perceived loss of SA from the lack of party line communication when using Data Comm. However it should be noted that there were no cockpit displays to assess possible mitigations. [9]

The EMMA2 operational taxi trials in Europe found using CPDLC messages with cockpit displays while taxiing on the airport surface improved the flight crew's SA and their workload was maintained. [13][14]

A study by NASA called "The Effects of Advanced Navigation Aid and Different ATC Environments on Task-Management and Communication in Low Visibility Landing and Taxi" showed that an electronic moving map significantly enhanced SA when using Data Comm, and reduced both intra-cockpit and controller-pilot Voice communications. [29]

A study reviewed multiple research efforts in 1999 and identified the following problems with Voice communication: data are transmitted sequentially, background noise and dialect, congestion, long or complex messages are prone to being misunderstood. The same study identified the following benefits of Data Comm communication: higher efficiency, unloads memory, improves message delivery time, improves transfer of information to other ATC and flight deck systems. However, the challenges Data Comm presents include: reduced SA due to loss of "party-line" Voice communication, inability to multi-task while responding to Data Comm, decreased head up time, and that cockpit graphical displays appear to improve head up time when Data Comm is used. [30]

2.9 Simultaneous Use of Voice and Data Comm

The controllers in the LINK2000+ Real-Time Simulation Project reported "[i]t was difficult to mix the two ways of giving instructions (Voice and Data Comm)". [9]

Results from the pilot debrief during the D-TAXI operational trials at Brussels from August 2006 through February 2007 found the requirement for the flight crew to respond with both Data Comm and Voice was considered impractical. [10]

A NASA simulation in 2003 was conducted that compared how flight crews handled Voice and Data Comm messages in a single medium versus a mixed medium. The interval between messages was also varied to examine the influence of time pressure. Results indicated that for messages sent via Voice, transaction times were lengthened in the mixed media environment. Furthermore, when time pressure was introduced, the mix of Voice and Data Comm did not necessarily capitalize on the advantages of both media. [31]

A NASA simulation experiment using twenty-four experienced commercial pilots explored various communication modes to understand the impact on decision making, workload, and SA. "The Evaluation of Mixed Mode Data Link for NextGen" experiment used Voice redundant to Data Comm (ATC and pilot always use both), Voice supplement to Data Comm (pilot always uses both), Data Comm only, and Data Comm with display showing aircraft intent. This research indicated that Data Comm alone was not always the optimal solution. When pilots read back the Data Comm message over Voice, the pilots committed fewer errors and their SA was increased. This research looked at the pilot's performance, and did not examine the entire operational interaction with controllers. [32]

2.10 Experiment Design Decisions from Literature Review

The following experiment design decisions were made, driven by the literature review documented in the previous paragraphs of this section:

1. Data Comm will be used for normal communication (taxi clearances, altimeter settings, frequency change, etc.), and Voice for time-critical, safety-related, or non-normal situations (takeoff clearance, landing clearance, crossing an active runway, etc.).
2. Some events will occur during the experiment that have ATC simultaneously issuing both Voice and Data Comm instructions, and the flight crew will respond to questions about this event.
3. Voice communication will have priority over Data Comm to ensure there is no ambiguity between the two communication modes.
4. The CDU will be the flight crew's interface for the Data Comm system.
5. The flight crew will be able to 'auto-load' the Data Comm clearance into the FMS and display that route on the Multi-Function Display (MFD).
6. Data will be collected on flight crew interaction with Data Comm in terms of time to respond, workload, acceptability, and understandability.
7. Data Comm messages coupled to graphical displays for the flight crew will be an Independent Variable.
8. Loss of situation awareness due to use of Data Comm will be measured, to include the impact of graphical displays coupled to the Data Comm message.
9. Oculometers will be used to collect head up time for both the PF and the Pilot Monitoring (PM) to create a more complete understanding of flight crew interaction with Data Comm. Independent oculometer systems will be used to accurately capture different cockpit tasks of the PF and PM.

3 Methodology

3.1 Experiment Hypotheses

The following high-level hypotheses drove selection of variables:

H1: Pilot workload and situation awareness will differ significantly between Voice and Data Comm communication modes.

- This hypothesis drove evaluation of the effect of Data Comm communications modality employment on flight crew workload and SA during taxi-in and taxi-out operations.

H2: Pilot workload and situation awareness will differ significantly between display modes when using Data Comm.

- This hypothesis drove evaluation of the influence of graphical display of airport and ownship route on crew workload and SA in a Data Comm environment.

H3: Pilots will rate the Data Comm used within this experiment as operationally acceptable.

- This hypothesis drove determination of the acceptability of Data Comm communications in the flight deck during operations in the terminal area. Acceptability was assessed in the context of expected, actual, and amended D-TAXI clearances during surface operations, and expected taxi clearances and other strategic CPDLC messages while on approach.

In addition to addressing the high-level hypotheses, the design of the study also permitted examining the following (specific metrics listed in Section 3.5):

- Message response times by type of Data Comm message
- Vehicle performance indices, such as Nose Wheel Steering (NWS) and taxi speed
- Workload and situation awareness of both PF and PM
- Acceptability of Data Comm messages at "High", "Medium", and "Low" altitude bands during arrivals
- Assessments of head up time for each crew member across the experimental conditions
- Objective data and subjective responses broken down by inflight and surface segments
- Objective data and subjective responses broken down by arrival and departure scenarios

3.2 Independent Variables

The literature review identified several key issues associated with Data Comm that could form independent variables. From these issues, two were selected by the FAA and NASA Team for inclusion in this study: Communication Modality (Voice, Data Comm) and Map Display Methodology (Paper, Moving Map Display (MMD), MMD+Route).

Thus, two component studies were chosen to efficiently and effectively incorporate both variables within time and resource constraints. The first of these (Study 1, or S1) assesses the differences in pilot acceptability of communications using two different modalities (Voice and Data Comm), and the second (S2) investigates the effect of map display methodology on the acceptability of Data Comm. The combination of communication modality and display methodology defines the four experimental conditions shown in Table 1 in Section 3.4.

3.2.1 Communication Modality

Communication modality addresses how information is transmitted from controllers to the flight crew. The use of Voice by exception was consistent with the Data Comm Tower Human-in-the-Loop (HITL) Simulation at the FAA Research Development & Human Factors Laboratory (RDHFL).

Two options were selected:

a. Voice only for controllers and flight crew. This condition serves as the baseline condition representing present-day operations.

b. Data Comm for controllers and flight crew, with Voice used by exception for time-critical or safety-related information.

(1) Data Comm was used to issue:

- taxi, expected taxi, and amended taxi instructions,
- gate pushback time,
- engine start clearance,
- notification of new altimeter or new Automatic Terminal Information Service (ATIS) information,
- radio frequency change to the next air traffic controller.

(2) Voice transmissions were used on departures to:

- initiate aircraft taxi (Ground),
- hold short of an active runway (Ground),
- cross an active runway (Tower),
- provide clearance to position and hold on the takeoff runway (Tower).

(3) Voice transmissions were used on arrivals for:

- traffic call-outs during arrival (Approach),
- initial check-in on tower frequency (Tower),
- clearance to land (Tower),
- initial check-in and clearance to taxi (Ground).

3.2.2 Display Methodology

Display methodology addresses the depiction of airport layout and taxi route with respect to ownship position on the Navigation Display (ND) in the Surface Depiction Mode. Three options were selected:

a. Paper where the flight crew had only a paper copy of the airport diagram.

b. MMD where taxiways, runways, signage, and ownship position was shown on a Moving

Map Display.

c. MMD+Route included everything in Option b., as well as a graphical display of the expected and actual ownship route clearance.

3.3 Scenario Descriptions

The scenarios were arrival and departure operations at Boston Logan International airfield, and utilized a combination of current published instrument procedures and clearances given by controllers. Furthermore, the taxi operations were aligned with related research being conducted by the FAA at the WJHTC RDHFL. A complete list of the scenarios, run order by crew, altitude that Data Comm messages were sent, taxi routes, and arrival procedure (if appropriate) are described in Appendix B.

3.3.1 Airport

The Boston Logan International airport (KBOS) (Figure 1) was used to align this research of the impact of Data Comm to flight crews, with FAA research studying the impact of Data Comm to controllers.

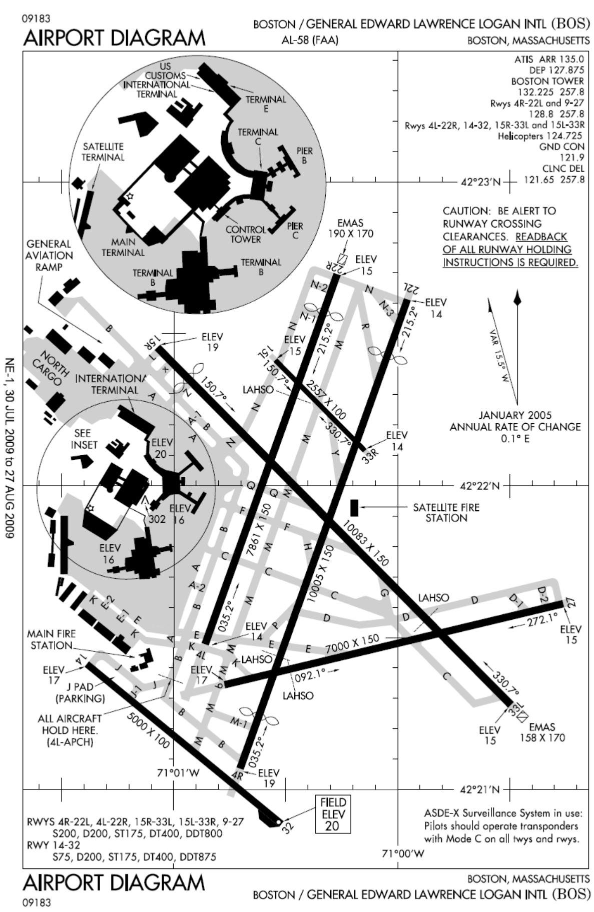


Figure 1. Boston Logan International airport diagram

3.3.2 Arrival Routes and Instrument Approaches

Arrivals to Runway 27 and Runway 33L were created that provided realistic profiles and workload from 18,000 feet to landing. An overview of the routes (fixes associated with the NORWICH THREE and SCUPP FOUR Arrivals) is presented in Figure 2.

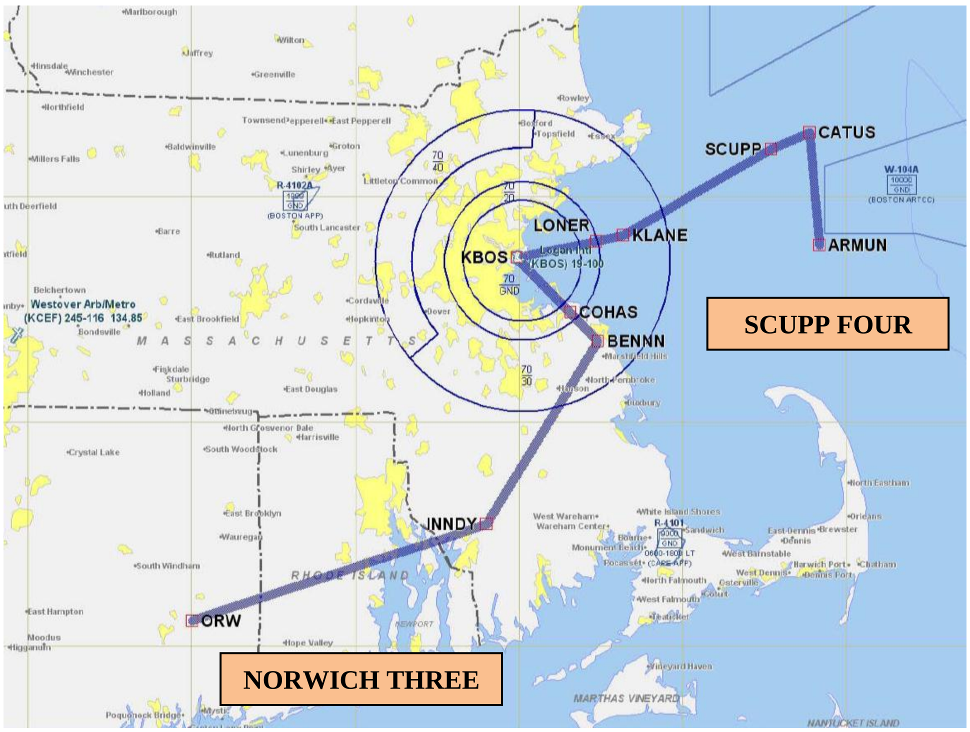


Figure 2. KBOS airspace and arrival routes

More specifically, portions of existing Standard Terminal Arrival Routes (STAR) were connected to a particular Instrument Landing System (ILS) approach based on current controller procedures. The routes were:

- NORWICH THREE Arrival, KENNEDY Transition (Figure 3).
  - This procedure starts Southwest of the airport. The scenario itself started overhead Norwich and proceeded East to INNDY, then direct to the Initial Approach Fix (BENNN) for the ILS to Runway 33L.
- SCUPP FOUR Arrival, KENNEDY Transition (Figure 4).
  - This procedure starts East of the airport. The scenario itself started overhead ARMUN and proceeded West to SCUPP, then a clearance for the ILS to Runway 27.

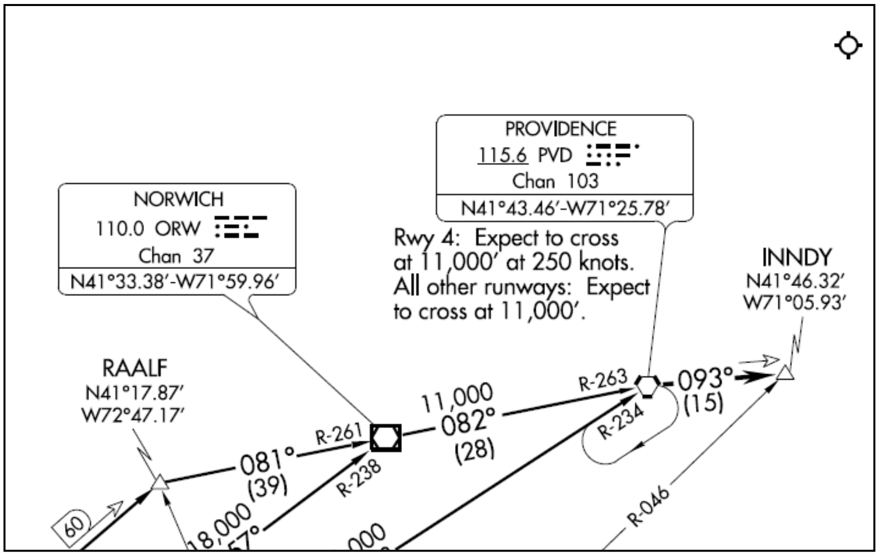


Figure 3. Excerpt of NORWICH THREE arrival

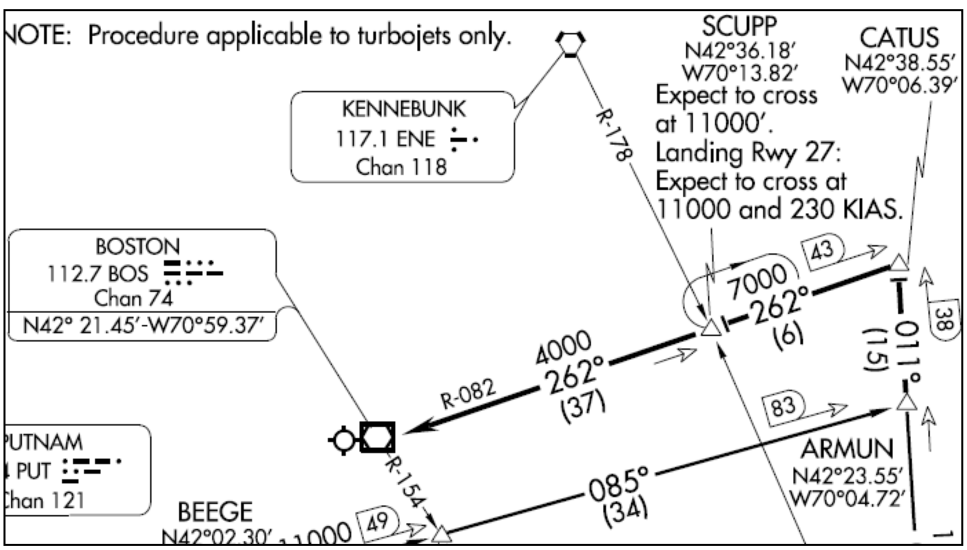


Figure 4. Excerpt of SCUPP FOUR arrival

3.3.3 Taxi Routes

Arrival taxi routes from Runway 27 ended at Terminal B, and arrival taxi routes from Runway 33L terminated at Terminal E (listed in Appendix B, Section 2). To align with research conducted by the FAA at the WJHTC RDHFL, departure taxi routes were selected from Terminal E-8A at the Northwest corner of Terminal E to the departure end of Runways 27 and 33L (listed in Appendix B, Section 3).

3.4 Experiment Design

Table 1 presents the experimental design matrix. Each of the four populated cells in the matrix had an associated arrival and departure scenario, creating the eight scenarios indicated in Table 2. Unpopulated cells (indicated by shading) were removed from the experiment since they were not essential in addressing the FAA questions, and to accommodate time and funding limitations. The column "Data Comm" refers to a communications modality where the primary mode is Data Comm; however, Voice was used for initiation of aircraft movement, aircraft check-in on Tower and Ground frequencies, runway crossing, and position and hold clearances.

The populated cell for "Paper" and "Voice" was the baseline case in terms of workload and situation awareness, representing typical airline transport operations in a present-day (2010) environment. The crew saw approximately 15 static aircraft and 20 moving aircraft (with the appropriate Voice communication between controller and pilot) during each 15 to 20 minute scenario, approximating a busy 78 aircraft arrival day at KBOS. Thus, incorporation of expected or amended taxi clearances in a present day Voice communications environment, while not unheard of, represents atypical operations and therefore was not implemented in this experiment design.

During Data Comm scenarios, the experiment was specifically designed to present a worst-case operational scenario. Four Data Comm messages were sent within two minutes of each other (2 "Expected Taxi" messages, 1 Altimeter, 1 change to the ATIS) while the crew was intentionally distracted. These distractions included ATC Voice call-out of factor traffic during arrival scenarios and researchers providing updated aircraft weight numbers during taxi that required the PM to use the FMS to recalculate takeoff speeds during departure scenarios. The second study held constant the modality of messages (Data Comm) but varied the display methodology over three display conditions: paper, moving map, and moving map with the graphical presentation of the ownship taxi route on the ND.

Table 1. Experimental design matrix

	Voice	Data Comm
Paper	Baseline 1 (S1/S2)	Baseline 2 (S1/S2)
MMD		S2
MMD+Route		S2

Baseline 1: Pilot performance with present-day Voice communications and paper airport diagram

Baseline 2: Pilot performance with Data Comm and paper airport diagram

Study 1 (S1): Assess and compare the acceptability of two communications modalities (Voice and Data Comm) while using paper airport diagrams.

Study 2 (S2): Assess and compare the effect of Map Display Methodology while using data communications on the acceptability of Data Comm.

Table 2 below contains the scenario types used for each study, and defines the flight phase, communication mode, and display methodology.

Table 2. Scenario types

Type	Flight Phase	Condition		Study S1 (Comm)	Study S2 (Display)
		Comm Mode	Graphical Display		
0	Arrival	Voice	Paper	Baseline	
1	Arrival	Data Comm	Paper	X	Baseline
2	Arrival	Data Comm	MMD		X
3	Arrival	Data Comm	MMD+Route		X
4	Departure	Voice	Paper	Baseline	
5	Departure	Data Comm	Paper	X	Baseline
6	Departure	Data Comm	MMD		X
7	Departure	Data Comm	MMD+Route		X

These eight scenario types were replicated so that each crew was exposed to 16 runs. Runs were ordered so that modality/display methodology conditions were not repeated within 3 runs, with arrivals and departures alternating as much as possible. Run conditions for the first eight runs were replicated exactly for the second set of eight runs for all crews. Different run orders were assigned to different crews to counterbalance the serial position of scenarios over the course of the experiment. In addition to these 16 runs, a rare event scenario run was conducted as the final run, unbeknownst to the crew. This last run supported an exploratory study described in Section 6.

3.5 Dependent Variables

The Dependent Variables for this experiment were:

- Workload
- Situation awareness (SA)
- Acceptability

Metrics used to quantify the dependent variables included the following:

- Data Comm message response times
- Flight crew technical performance: NWS control rate, taxi speed, flight director error
- Workload: Bedford Workload Scale, pairwise comparisons of workload by display type
- Situation Awareness: Situation Awareness Rating Technique (SART), pairwise comparisons of SA by display type
- Acceptability: subjective, self-rating
- Crew Resource Management: flight crew errors, or mitigation of potential errors
- Head up time: both PF and PM
- Trust: model-based errors and response-time metrics, questionnaire items derived from previous research, and open format interviews

3.6 Parameters and Data Analysis Techniques

3.6.1 Data Comm Message Response Time

Data Comm message response times were calculated as the difference in seconds from the time that the message was initially received (chime annunciated, and “ATC MESSAGE” shown on upper Engine Indicating and Crew Alerting System display), and the time that a response button (“WILCO”, “ROGER”, or “UNABLE”) was depressed on the message ATC Uplink Page 2. Message response times were averaged for each crew, and for all crews, by modality and message type. Response times were also analyzed by distribution, and in categories requested by the FAA Data Comm group.

3.6.2 Flight Technical Performance

For both arrivals and departures, NWS rate in degrees per second was analyzed using the Power Spectral Density calculated for the frequencies of 0.1 to 2.0 Hz(i.e., over a frequency range where significant NWS corrections would be made). For arrivals, the calculations began when the aircraft taxi speed was first below 80 knots. For departures, the calculations began when the taxi speed was first above 0.5 knots.

Average taxi speeds were also calculated for arrivals - from when taxi speed was first below 30 knots through the end of run - and for departures, from when taxi speed was first above 0.5 knots through the end of run.

Since a precise path was not defined during periods where any Data Comm messages were being handled (messages were given prior to the Final Approach Segment during arrivals, and pilots are not required to precisely follow yellow taxi lines during surface operations), the PF flight technical performance was analyzed, rather than flight technical error. Flight technical performance during arrivals was defined as the average flight director deviation from null, determined over one of the three altitude bands where Data Comm messages were received. The specific altitude bands were ‘High’ (16,000 - 14,000’ MSL), ‘Medium’ (10,000 - 8,000’ MSL), and ‘Low’ (7,000 - 5,000’ MSL), and were chosen to represent various states of crew workload. Crew workload was not considered significantly different between these altitudes.

3.6.3 Head Tracking

Head tracking data were analyzed to determine each pilot’s head up time over each test run. Pilot head up time was determined using a combined measure approach using both eye gaze and head position. If the eye gaze vector was present, head up was counted if the point of gaze was located out the window. If eye gaze was not available, determined by an eye gaze quality of less than 50%, head position was used to assess if the pilot was head up using a head pitch threshold specific to that subject on that run. To calculate the head pitch threshold, average head pitch was calculated when point of gaze was out the window. This approach was taken to maximize the number of data points usable for analysis due to head tracking being more stable across subjects than eye tracking.

Head tracking analysis for each pilot was broken up into several phases. For all conditions, head up time was calculated for four bands on arrival scenarios, aligning with the three Flight Technical Performance altitude bands (High, Medium, Low) and approach taxi (< 80 knots to end of scenario). Departure scenarios were analyzed from beginning of taxi (> 0.5 knots) to the end of the scenario.

Statistical analyses were performed to identify significant difference across modality and between crew role (PF/PM), as well as the interaction of the modality and crew role. Used in conjunction with an Analysis of Variance (ANOVA), Tukey Honestly Significant Difference (HSD) pairwise comparison tests were performed to determine significant differences between multiple comparisons of modalities. These tests compare all possible pairs of statistical means of the individual modalities against the standard error of the data distribution, determining if the difference between means is significantly different from the general observations in the tested dataset.

3.6.4 Biographical Data Questionnaire

The Biographical Data Questionnaire (Appendix C) was acquired detailed information about each pilot's experience. Questions focused on age, overall flight time in a cross section of aircraft, flight time in Boeing 757 or comparable aircraft, military time, experience with Data Comm messaging, and any flight experience flying into and out of KBOS. Results are shown in Section 3.10.2, Subject Pilot Experience Level.

3.6.5 Post-Scenario Questionnaire

The Post-Scenario Questionnaire (Appendix D) was given to both subject pilots after each scenario, and consisted of the Bedford Workload Scale [34], the Situation Awareness Rating Technique (SART) [35], and questions addressing crew coordination, acceptability and trust. This questionnaire was given electronically on a personal tablet computer while the subject was seated in the simulator. The Bedford Workload Scale is a uni-dimensional rating scale designed to identify operator's spare mental capacity while completing a task. The single dimension is assessed using a hierarchical decision tree (always completely visible to the subject) that guides the operator through a ten-point rating scale, each point of which is accompanied by a descriptor of the associated level of workload. It is simple, quick and easy to apply in situ to assess task load in high workload environments, but it does not have a diagnostic capability.

A SART was also administered after each run. SART provides an assessment of the SA based on a pilot's subjective opinion. SART incorporates three dominant components: demand on the pilot's resources, supply of resources, and understanding of the situation. These were determined to be relevant to SA through an analysis with pilots. Pilots rated their perception of the impact of these components using bipolar scales from 1 to 7. These scales were then transformed using the formula:

$$\text{SA} = \text{Understanding} - (\text{Demand} - \text{Supply})$$

to provide an overall SART score for a given system. The range of scores from the application of the formula is from -5 for extremely low SA to 13, extremely high SA.

Additional questions were also given on the Post-Scenario Questionnaire pertaining to where the crew received their Data Comm information, crew interaction, acceptability of receiving Data Comm messages, and their trust in the system. The trust questions were derived from previous research in which the issues of confidence, risk, accuracy, verification need, and time constraints were investigated. These elements of trust were found to be valid in several research efforts in which subjects were asked to identify concepts that they affiliated with the construct of trust. In addition, other research from which questions were drawn focused on the operators' perception of risk associated with too much trust in automation.

Six questions were developed to assess the Crew Resource Management (CRM), or interaction and coordination of crew members on the flight deck. Questions were formulated based upon FAA Advisory Circular 120-51E, *Crew Resource Management Training*, particularly the crew performance marker clusters. The questions ask pilots to assess themselves individually in terms of their performance during the scenario, their perception of their crewmembers performance, the level of communication and related

SA throughout the scenario, and their subjective analysis of crew role responsibility adherence.

Levene's test for equal variances on six of the thirteen post-scenario questionnaire scales failed the assumption of equal variances ($p \geq 0.10$); and of those that did not fail Levene's test, all but two showed distribution distortions where either skew or kurtosis exceeded +/-2. Consequently, analyses for these items were conducted using non-parametric statistics. When necessary, results were analyzed separately to determine if display conditions differed for pilots, and then for copilots; and a separate analysis was performed to determine if, aggregated over display conditions, pilot and copilot ratings significantly differed.

3.6.6 Post-Experiment Questionnaire

The Post-Experiment Questionnaire (Appendix E) compared workload and SA between various scenarios and asked specific questions regarding the acceptability of using Data Comm at various altitudes. Additional questions were asked regarding crew coordination, the overall assessment of the experiment, the use of Data Comm, and suggestion for improvements to the messages or displays.

Pilot crews were asked at the completion of the experiment to compare their perceived support for effective CRM and crew coordination experienced among scenarios. Each pilot of the crew assessed the SA difference experienced through using one modality versus another, indicating which modality had the greatest effect on their ability to effectively coordinate as a team, distribute their attentional resources, and ensure shared SA. Responses to this qualitative questionnaire also provide insight into the interaction effect of crew role and modality, as well as basic pilot modality preference.

These data were analyzed according to the Analytical Hierarchy Process (AHP), which provides percentile preferences for options considered, as well as a consistency ratio of subject preferences. The preference percentiles averaged over participants in each crew role. Arcsin (square root) transformed percentile data was analyzed for equal variances among conditions. Levene tests for all dependent measures were non-significant ($p > 0.01$), and all skew and kurtosis measures were within +/-1.05 (with standard errors of 0.257, and 0.508, respectively). Analyses of variance were conducted for each dependent measure testing for differences in preference by condition and crew role (PF and PM).

3.6.7 Post-Experiment Debrief

A semi-structured verbal debrief session was held after the Post-Experiment Questionnaire was complete. This session was recorded and generally lasted between 45 to 90 minutes, and loosely followed the format of the Post-Experiment Questionnaire and specific items the researchers had noticed during that particular crew's scenarios.

3.6.8 Audio and Video Recordings

Audio and video recordings were made for each of the runs for each crew. Audio recordings were made of the post-experiment crew debrief. Recordings were subsequently analyzed to assess crew performance, opinion, crew resource management, and crew errors.

3.7 Research Facilities

3.7.1 Hardware and Software Configuration

NASA Langley Research Center's Integration Flight Deck (IFD) Simulator (Figure 5) was used, with a Boeing 757-200 vehicle model, and an environmental simulation of KBOS, as well as navigation and communication facilities within an approximate 50 mile radius from the airport.

Figure 5. Integration Flight Deck simulator

The IFD full-mission simulator is a duplicate of a standard Boeing 757-200 aircraft cockpit and is driven by a Boeing 757-200 aircraft dynamics mathematical model. The cockpit includes standard ship's instruments representative of a line operations Boeing 757-200 aircraft. The main instrument panel contains the Primary Flight Display (PFD), ND, Engine Indicating and Caution Alerting System (EICAS), flight instruments (airspeed, altitude, attitude, etc), as well as standby altimeter and gear lever. The center control stand consists of a typical B-757 throttle quadrant, flap and speed brake controls, reverse thrust, spoiler handles, dual FMS CDUs, several electronic panels for controlling the PFD and ND, as well as researcher specified systems. The IFD houses a standard Mode Control Panel (MCP) under the glare-shield, and a complete overhead panel.

The cockpit's visual system is a panorama system using five video projectors that provide 200° horizontal by 40° vertical field-of-view, with 1440 x 1024 pixel resolution. The visual scene used for this experiment was the KBOS terminal environment in a day, Visual Meteorological Conditions (VMC) setting. Up to 20 moving aircraft, and 15 static aircraft were depicted in the arrival and surface taxi scenarios, and this traffic was accurately projected in the out-the-window (OTW) displays, and shown on the moving map display, as appropriate for that run condition.

3.7.2 Additional Simulation Capabilities

In support of this experiment, the following hardware and software additions to the IFD baseline configuration were incorporated:

- MMDs, presentable on the NDs at both crew stations, with the capability to display ownship cleared route.
- Electronic Flight Instrumentation System (EFIS) controls at both crew stations, to control scale and display mode for the NDs. Display mode selection allowed crews to see an airport depiction, with expected taxi route, while airborne during the simulated approach.
- The capability to trigger the playing of researcher-provided audio wave files, based on simulated aircraft position, range to traffic, and/or specified cockpit control actuation (such as microphone transmit release).
- Additional selectable pages on both FMS CDUs, to support a hierarchical Data Comm uplink and downlink capability, as well as the capability to selectively load expected or cleared routes into the MMDs.
- The capability to simulate (visually OTW) push-back from the terminal gate.

A Rockwell Collins EP-1000 KBOS database was used for OTW projection of the airport surface, taxiways, runways, buildings, obstructions, signs, and airport terrain and cultural features. The IFD simulation also used the appropriate database to provide accurate location and frequency of navigation aids, in particular the ILS RWY 27 and ILS RWY 33L. Frequencies aligned with published charts and pre-recorded Automatic Terminal Information Service (ATIS) messages were used based on environmental conditions and airport status for the particular scenario. The IFD employed a navigation and communications simulation that permitted realistic voice communication, as well as accurate navigation and flight crew position awareness during standard arrivals, appropriate to each scenario.

3.7.3 Oculometer Hardware and Software

A ten-camera oculometer system (Appendix F) was installed in the IFD to support unobtrusive collection of eye tracking and head position data for both flight crew subjects. This Smart Eye Inc. eye tracker uses a remote eye tracking system with facial recognition to calculate the position of defined points on a subject's head relative to the calibrated position of two or more cameras. The cameras used the facial features to locate the corners of each of the subject's eyes and digitally zoomed to enhance the image of the eye.

3.8 Data Comm Messages and Displays

The general Data Comm message format and content is documented in Appendix G and was derived from Section 5 of Reference [33]. The specific Data Comm uplink messages based on those documents used in this experiment are listed in Appendix H. Each of the 11 crews received 96 Data Comm uplink messages (1056 total for all crews), and the crews had to respond with a downlink message to each one. The aggregate count of these messages per crew and over the entire experiment is tabulated in Table 3.

Table 3. Data Comm messages per crew and entire experiment

Departure Data Comm messages	Per Crew	Total
• Push back	6	66
• Start	6	66
• Expected D-TAXI	12	132
• D-TAXI	6	66
• Amended D-TAXI	6	66
• Cross Active Runway	6	66
• ATIS	6	66
• Altimeter	6	66
Departure sub-total:	54	594
Arrival Data Comm messages	**Per Crew**	**Total**
• Expected D-TAXI	12	132
• ATIS	6	66
• Altimeter	6	66
• Frequency change	6	66
• D-TAXI	6	66
• Amended D-TAXI	6	66
Arrival sub-total:	42	462
Total:	**96**	**1056**

Data Comm message format and page architecture were modeled after the Boeing 747-400 Future Air Navigation System 1/A (FANS-1/A) implementation. Display shapes, sizes, and colors on the ND were based on on-going research at NASA Langley, the proposed Data Comm standards [33], and discussions between members of the FAA and NASA Data Comm team.

The flight crew accessed Data Comm messages by depressing the CDU button labeled 'ATC' (located on the top row of the CDU menu page selections, Figure 6), which caused the 'ATC Index' page to be displayed on the CDU screen (left side of Figure 7). The 'Prev Page' and 'Next Page' CDU buttons (fourth row of Figure 6) were used by the flight crew to access the different pages of the CPDLC message, with the ability to send a CPDLC response always on the last page of the message (right side of Figure 8).

- Depressing the 'Request' key on the 'ATC Index' page (left image of Figure 7) accesses the ATC Request page (shown on the right side of Figure 7).

- Depressing the 'Log' key on the 'ATC Index' page accesses the 'ATC Log' page (left side of Figure 8).

- Depressing any button on the right side of the ATC Log (left side of Figure 8) brings up the respective Data Comm message, such as the D-TAXI messages in the next three figures (Figures 9-11).

- Depressing the "Next Page" button (a separate button on the CDU panel) from the ATC Log page, reached the second page of the Data Comm message where the downlink response could be sent by the crew (right side of Figure 8).

Figure 6. Control Display Unit (CDU)

Figure 7. ATC Index (left) and ATC Request (right) pages

Figure 8. ATC Log (left) and Downlink Response (right) pages

Three types of routes are shown on the MMD in Figure 9, Figure 10, and Figure 11 that correspond to the three types of Data Comm D-TAXI messages. For these scenarios (MMD+Route display methodology), taxi routes were loadable on each crew's MMD, when either FMS CDU load button was pressed (left side of Figure 9, bottom-left key). Once loaded, the routes were not removable, except by replacing them with a new route.

Expected D-TAXI routes for flight crew planning purposes were labeled "Expect Taxi" on the CDU, and depicted in dotted cyan on the ND (Figure 9). The CDU shows the message has been received and loaded, but a flight crew response has not yet been sent, so the status is depicted as "OPEN" on the CDU. Runway hold short bars were intentionally not shown with Expected D-TAXI route to differentiate them from D-TAXI uplink message. After the response was sent by depressing "Next Page" and then the line select key for "ROGER" (Page 2 shown in Figure 8 right side), the expected taxi route depiction on the ND did not change however the status on the CDU Page 1 changed from "OPEN" to "ROGER".

Figure 9. Open Expected D-TAXI message on CDU (left) and display on ND (right)

Taxi instructions sent by Data Comm that the flight crew had not yet responded to were called Proposed D-TAXI, and were depicted as a dotted white line with runway hold short bars shown in red (Figure 10). The remainder of the route after the red hold short bar was shown in dotted cyan. For this message, the message text on the CDU read “Taxi To” instead of “Expect Taxi To.” In this case, the route displayed (indicated by a dotted white line) changed to a cleared taxi route once a “WILCO” response had been sent (Figure 11). After a “WILCO” downlink was sent by the crew, the cleared taxi route was depicted in solid magenta to the first red hold short bar, with the remainder of the route after the red hold short bar remained in dotted cyan. Page 1 of the CDU was also changed to show “WILCO”. (Note: “ROGER” was used as the flight crew response for the “Expected D-TAXI” message since that message was informative, as were messages for altimeter settings and weather information. “WILCO” was used for “D-TAXI” and radio frequency change messages since they are directive.)

Figure 10. Open D-TAXI message on CDU (left) and display on ND (right)

Figure 11. Accepted D-TAXI message on CDU (left) and display on ND (right)

Amended D-TAXI instructions followed the same protocol as Proposed D-TAXI instructions. The text on the CDU displayed “Amended Clearance” and status as Open, while the ND displayed the current taxi route was a solid magenta line, with any proposed changes as solid white lines (Figure 12).

Figure 12. Open Amended D-TAXI message on CDU (left) and display on ND (right)

The status of the message would change from OPEN to WILCO when the flight crew sent a Data Comm response, and the ND displayed the new route as a solid magenta line (Figure 13).

Figure 13. Accepted Amended D-TAXI message on CDU (left) and display on ND (right)

3.9 Experiment Protocol

Prior to the experiment, the subject pilots were scheduled and paired with others from the same flight organization. This tended to minimize adverse effects from differing standard operating crew procedures or crew resource management principles inherent in different airlines. To the maximum extent practicable, all crews used standardized, pre-briefed procedures. During the experiment, the pilot qualified as a Captain performed the role of the PF in the left crew station and was responsible for control of the simulated aircraft throughout the experiment. The pilot qualified as a First Officer performed the role of PM in the right crew station and had primary responsibility for Data Comm messages for the duration of the simulation experiment. The First Officer was the PM throughout the entire experiment to increase the statistical significance of collected data.

Subject pilots arrived at the research facility by 0745 on the first day and completed required paperwork. At 0800 the formal briefing began with completing the informed consent form required by NASA's Institutional Review Board, followed by a two hour training program (Appendix I). The training covered the purpose of the experiment, interactive practice sending and responding to Data Comm messages, a walk-through of each scenario, and practice completing the electronic questionnaires. From approximately 1000 to 1230, the subject pilots were in the IFD for part-task training and completed the four training scenarios. After lunch, the first group of eight runs was accomplished, usually finishing by about 1730. The second day began at 0800 with the second group of eight scenarios (replicate of the first group), and finished by 1200. Prior to the beginning of each scenario, the crews were given a verbal briefing about the upcoming scenario (Appendix J). After each scenario (departures lasted about 15 minutes and arrivals about 20 minutes), five to ten minutes were required for the crew to answer the electronic questionnaire and the researchers to reconfigure the cockpit for the next scenario. After every third or fourth scenario, a break was taken to ensure the subjects were well rested. Following the last scenario, the subject pilots were brought back to the briefing room where they completed the post-experiment questionnaire on paper, generally taking 20 to 30 minutes. Following that, a semi-structured verbal debrief was held with the research team and the subject pilots, frequently lasting up to 90 minutes.

3.10 Subject Pilots

3.10.1 Requirements

NASA recruited subject pilots in support of this simulation experiment, and complied with all applicable procedures and laws relating to protection of human participants as specified by the Institutional Review Board. The following were specific requirements for all participant pilots:

- A US citizen or Permanent Resident status
- A valid FAA Airline Transport Pilot certificate
- Currently employed by a Part 121 air carrier or manufacturer
- Preference was given to pilots that held a Boeing 757 or 767 type-rating, however, other type ratings with CDU/FMS incorporation that is similar to the 757 / 767 were considered
- Preference was given to pilots familiar with the FANS-1/A CDU controls, displays, and functionality through flight experience. However, pilots not meeting this preference were familiarized with FANS-1/A CDU during the training program portion of the experiment.
- All pilots had current or recent flight experience in the crew role they were assigned for the experiment (i.e., Captain or First Officer).
- A preference was given to subjects without hard edge bi-focal or tri-focal glasses.

Pilots were instructed to wear glasses only if/when absolutely necessary as there were detrimental effects to oculometer eye tracking ability depending on the type of glasses worn, specifically glasses with bi/tri-focal lenses. Head tracking was unaffected by the presence of glasses.

3.10.2 Subject Pilot Experience Level

Eleven crews of two pilots each participated in the study, with each crew comprised of a Captain and First Officer (FO) from the same airline. on the pilot experience data collected from the Biographical Questionnaire (Appendix C) are summarized in Table 4. All pilots were male with an average age of 48.6 years, and their total flying time ranged from 6000 to 24,000 hours with a mean of 13,832.5 hours. In the Boeing 757 or comparable aircraft type, their time ranged from 1000 hours to 15,000 hours with a mean of 7768.6 hours. Nineteen of the 22 pilots had conducted flight operations into and out KBOS, and approximately half of the pilots had some prior experience with Data Comm. Six Captains and four FO pilots wore glasses during the experiment.

Table 4. Subject pilot experience level in years and hours

	Mean Age	Low Age	High Age	Std Dev Age	**Mean Years Flying**	Low Years Flying	High Years Flying	Std Dev Years Flying
Captain	52.5	46.0	58.0	4.0	23.9	19.0	33.0	3.9
FO	44.2	37.0	56.0	5.6	15.0	10.0	26.0	4.8
	Mean Total Hours	Low Total Hours	High Total Hours	Std Dev Total Hours	**Mean B757 Hours**	Low B757 Hours	High B757 Hours	Std Dev B757 Hours
Captain	17614	13750	25000	3784	7255	1100	10000	3139
FO	11242	6600	19460	3391	5036	1100	10000	3032

4 Results and Discussion

This first part of Section 4 presents a summary of results of flight crew response time to Data Comm uplink messages (complete data in Appendix K), and the distribution of those response times (complete data in Appendix L). Section 4.2 presents flight crew technical performance results for the rate of Nose Wheel Steering inputs and aircraft taxi speeds (complete data in Appendix K). Section 4.3 discusses results from the two independent oculometer systems (complete data in Appendix N). Section 4.4 presents a summary of results from the Post-Scenario Questionnaire (complete data in Appendix O). Section 4.5 is a summary of results from the Post-Experiment Questionnaire (complete data in Appendix P). Section 4.6 presents a summary of results from the verbal debrief session held at the end of the experiment. In response to RTCA Special Committee 214 (SC-214), the flight crew CPDLC response times are published in a particular format to support their analysis in Appendix M.)

'N' in this paper is used as the number of events that occurred (for example, number of times the flight crew responded to a Data Comm message, or the number of responses received on a question).

4.1 Data Comm Message Response Time

Results from flight crew response to all Data Comm messages, excluding those that the crew took longer than two minutes to respond or were not responded to at all, are described in Section 4.1.1. The time distribution of these responses is presented in Section 4.1.2. The beginning of Appendix L contains the rationale for the two minute limit for flight crew responses to Data Comm messages, and lists by category the number of events that were excluded from analysis in the paper.

4.1.1 Response Times Based On All Data

Individual time to respond in seconds to Data Comm uplink messages are listed by crew in Appendix K. Figure 14 shows the mean of all flight crew Data Comm message response times by condition. Results show that the majority of analyzed response times were well under a minute (Mean = 20.7 seconds, SD = 17.6 seconds across all conditions). There were a few occasions wherein crews reviewed a message and agreed to its content but did not respond to the message within two minutes (5 of 369 (~1%) directive Data Comm messages, and 27 of 660 (~4%) informative Data Comm messages). Video review, researcher experience, and verbal debrief with subject pilots suggests that these long response or non-response events were cases wherein the crew simply forgot that the message had not been responded to, rather than workload prioritization and shedding. This result suggests that improving the operational ease of answering a message over the FANS-1/A standard would improve crew response to messages, and/or implementation of ATC message timeouts and re-sends should be considered in Data Comm implementation.

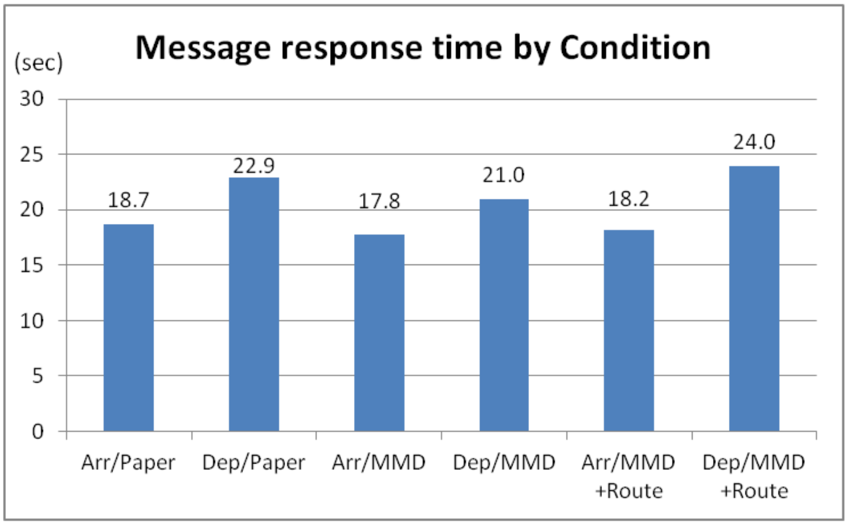


Figure 14. Message response time by condition

Table **5** and Table 6 show mean, standard deviation, and paired mean differences for message response time in seconds by condition. The analysis indicated a significant effect (F(5,1010)=3.777, *p*=0.0022), but is only evident between the two lowest (Arrive/MMD and Arrive/MMD+Route) and the highest (Depart/MMD+Route) times on the figure (α=0.05, HSD=5.47). However, this difference is not operationally significant. The remaining response times by Condition exhibited no statistically significant difference.

Table 5. Mean response time and standard deviation by condition

	Arrival / Paper	**Depart / Paper**	**Arrival / MMD**	**Depart / MMD**	**Arrival / MMD+Route**	**Depart / MMD+Route**
Mean (seconds)	18.7	22.9	17.8	21.0	18.2	24.0
Standard Deviation	14.6	20.4	15.7	16.6	12.8	21.2
N	146	188	153	197	147	185

Table 6. Pairwise comparisons of response time by condition (α = .05, HSD = 5.47)

	Depart / Paper	**Arrival / MMD**	**Depart / MMD**	**Arrival / MMD+Route**	**Depart / MMD+Route**
Arrival / Paper (seconds)	4.2	0.9	2.3	0.5	5.3
Depart / Paper		5.1	1.9	4.7	1.1
Arrival / MMD			3.2	0.4	6.2 *
Depart / MMD				2.8	3.0
Arrival / MMD+Route					5.8 *

NOTE: statistical significance indicated by *

Figure 15 shows a plot of the mean data, and Table 7 shows mean and standard deviation for message response time by display methodology (arrival and departure aspects of the conditions collapsed). The analysis indicated no significant differences (F(2,1013)=1.027, *p*=0.36) between any of the groups.

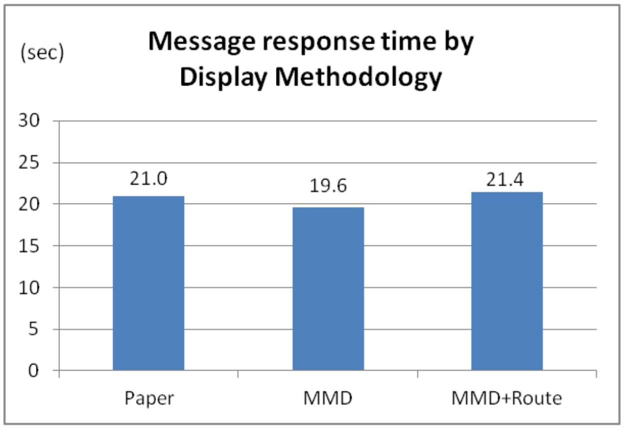


Figure 15. Response time by display methodology

Table 7. Mean response time and standard deviation by display methodology

	Paper	MMD	MMD+Route
Mean (seconds)	21.0	19.6	21.4
Standard Deviation	18.2	16.3	18.2
N	334	350	332

Additional analysis was requested by the FAA, and one of those requests was message response time by phase of flight. Figure 16 shows a plot of the mean data and Table 8 the mean and standard deviation message response times by arrivals (inflight and surface) and departures (surface only). The analysis indicated a significant effect ($F(1,1013)=15.85$, $p<0.001$), ($\alpha=0.05$, HSD=2.81, Mean Difference=4.4) between the two groups. Results of the analyses indicate departure operations had a statistically significant longer response times than arrival operations (although 4 seconds would not be operationally significant), with variations in response time due to display methodology being not significant.

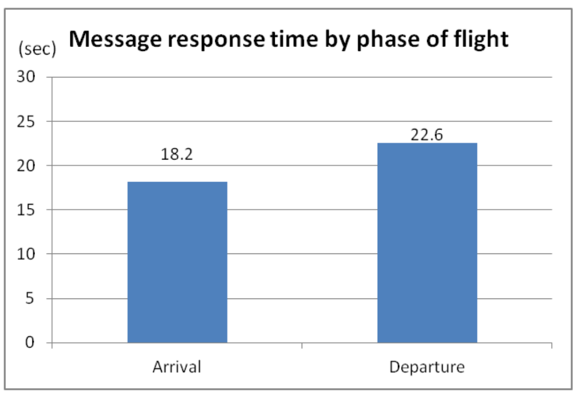


Figure 16. Message response time by phase of flight

Table 8. Mean response time and standard deviation by phase of flight

Phase of Flight	**Arrival**	**Departure**
Mean (seconds)	18.2	22.6
Standard Deviation	14.4	19.5
N	446	570

Figure 17 shows mean Data Comm message response times by message type. Statistical analysis of the mean response time by message type indicated a significant message type effect ($F(5,6)=12.683$, $p=0.004$), but only between certain message types (Information versus Frequency; Frequency versus Expected Taxi; Pushback and Start versus Expected Taxi; Expected Taxi versus Taxi; and Expected Taxi versus Amended Taxi). Table 9 shows mean and standard deviation by message type and Table 10 the difference between means for paired response times by message type. Analysis indicated a significant effect ($F(5,1010)=7.602$, $p<0.0001$), ($\alpha=0.05$, HSD=6.09, $p<0.05$) for all the comparisons involving Expected Taxi messages. The remaining response times by condition did not differ significantly.

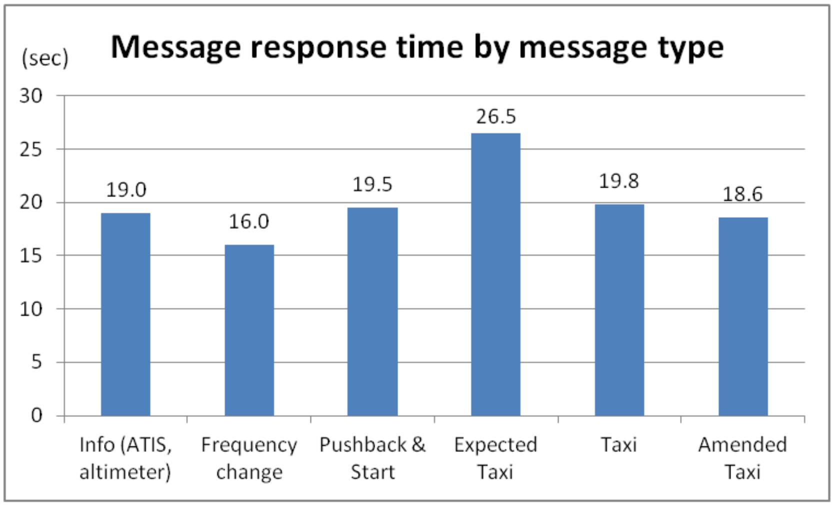


Figure 17. Mean response time by message type

Table 9. Mean response time and standard deviation by message type

Message Type	Info	Frequency	Pushback and Start	Expected Taxi	Taxi	Amended Taxi
Mean (seconds)	19.0	16.0	19.5	26.5	19.8	18.6
Standard Deviation	19.3	12.6	17.0	20.7	16.6	12.2
N	250	65	127	253	132	190

Table 10. Pairwise comparisons of response time by message type (α=0.05, HSD=6.09)

	Frequency	Push back and Start	Expected Taxi	Taxi	Amended Taxi
Info (seconds)	3.1	0.5	7.4 *	0.8	0.5
Frequency		3.6	10.5 *	3.9	2.6
Pushback and Start			6.9 *	0.3	1.0
Expected Taxi				6.6 *	7.9 *
Taxi					1.3

NOTE: statistical significance indicated by *

Researcher experience suggests that Expected Taxi message response times were somewhat longer because they were delivered during times of relatively high workload for the PM, and there was a perceived absence of operational urgency in responding to them. Taxi and Amended Taxi message response times benefited from the perception of operational urgency. The frequency change message was delivered during low workload for the PM (after configuration changes and checklists were complete).

4.1.2 Response Time Distributions

To address the FAA's request for time required for flight crew response, additional analysis was conducted that removed responses greater than two minutes and the results are presented in this Section with complete data available in Appendix L. Thirty-nine of the 1056 Data Comm uplink messages (approximately 4%) were not responded to within 120 seconds. In all cases, it appeared to the researchers that the root cause was that the pilots read the uplink message, mentally processed it, and were complying if appropriate, but believed either they had acknowledged the message or forget to acknowledge the message on the second page of the FANS-1/A implementation. This statistic and researcher observation is collaborated by crew debrief comments where they commented having to proceed to a separate page to respond led to occasional mistakes.

For Data Comm message response time within two minutes (N=1017) the distribution seen in Figure 18 shows that response times are not normally distributed, which is expected due to the left hand limit of zero seconds for response time. Heavily-peaked, positively-skewed distributions indicate that regardless of message type, pilots attempt to answer the message as soon as operationally possible, with rare situations arising when a message cannot be immediately answered, or the pilots believed they had acknowledged the message (see Appendix L for distribution by message type). From an operational standpoint, the distributive shape of response times suggest that the flight crew attempted to answer all Data Comm messages in an expeditious manner.

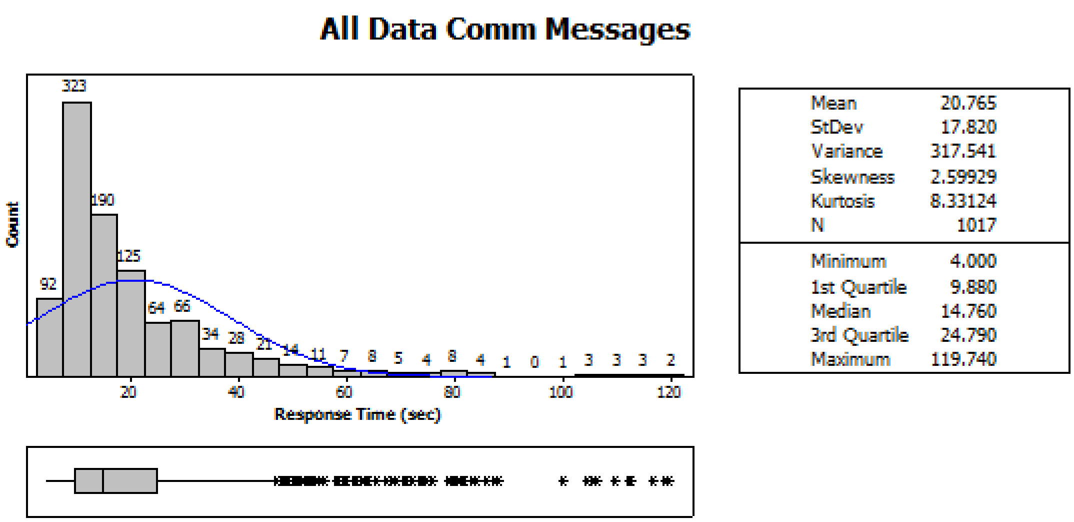


Figure 18. Distribution of flight crew Data Comm response times

4.2 Flight Technical Performance

The FAA requested additional data analysis to explore results based on arrival and departure scenarios; therefore, Section 4.2.1 and 4.2.2 include these analyses although they are not part of the original hypotheses. The PF Flight Director error data was collected and analyzed for the flight portion of the arrival scenarios; however, no statistical correlation or significance was found. Therefore, the summary of that data is presented only in Appendix K.

4.2.1 Power Spectral Density of NWS Rate

A statistical analysis was conducted on NWS rate Power Spectral Density (PSD) during arrival and departure taxi (individual crew performance shown in Appendix K). NWS PSD is a measure of control activity during taxi, which may be qualitatively related to PF (physical) workload. Analyses were conducted separately for arrivals and departures by condition, for Day 1 and 2 of the experiment, and for all arrivals and all departures. Figure 19 shows an average of NWS Rate Power Density Spectrum (degrees per second squared times frequency in Hz) for Arrival and Departure Scenarios, as a function of condition.

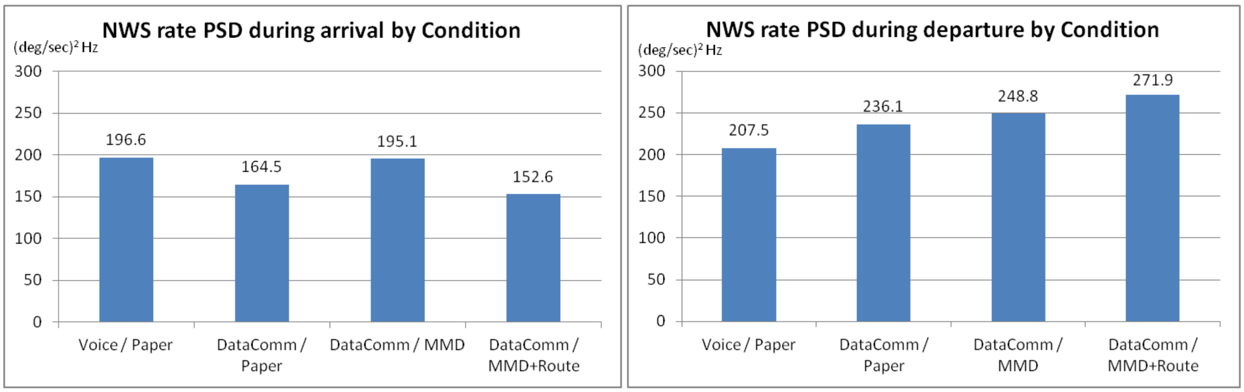


Figure 19. NWS rate PSD during arrival (left) and departure (right) by condition

NWS PSD analysis by condition for arrival scenarios:

Table 11 shows mean and standard deviation and Table 12 the paired mean differences for NWS PSD during arrivals by experimental condition. The Tukey HSD analysis indicated no significant difference (F(3,80)=3.388, p =0.022), (α=0.05, HSD=44.63, p<0.05) for any of the pairwise comparisons. Results during arrival operations show no statistically or operationally significant differences in NWS activity by condition.

Table 11. NWS PSD for arrival scenarios by condition

	Voice / Paper	**DataComm / Paper**	**DataComm / MMD**	**DataComm / MMD+Route**
Mean ((Deg/Sec)^2 Hz)	196.6	164.5	195.1	152.6
Standard Deviation	69.9	37.8	56.2	51.1
N	21	21	21	21

Table 12. Pairwise comparisons of arrival NWS PSD by condition (α=0.05, HSD=44.6)

	Data Comm / Paper	**Data Comm / MMD**	**DataComm / MMD+Route**
Voice / Paper	32.1	1.5	44.0
DataComm / Paper		30.6	11.9
DataComm / MMD			42.5

NOTE: no cell comparisons were statistically significant

NWS PSD analysis by condition for departure scenarios:

Table 13 shows mean and standard deviation, and Table 14 the paired mean differences for NWS PSD during departures by experimental condition. The Tukey HSD analysis indicated a significant difference (F(3,80)=4.959, p=0.0033), (α=0.05, HSD=44.88, p<0.05) between the Voice/Paper and Data Comm/MMD+Route conditions. No other paired comparisons were significant.

Results show an increase in NWS activity when going from Voice to Data Comm modality. Departure routes were relatively long (about 15 minutes) and complex (5-10 turns). It is possible that the decrease in head up time associated with reading and interpreting Data Comm clearances, as well as the compelling nature of the MMD and loadable routes, contributed to less time available for head up precise path control, and thus, greater NWS activity in making fine corrections.

Table 13. NWS PSD for departure scenarios by condition

	Voice / Paper	**DataComm / Paper**	**DataComm / MMD**	**DataComm / MMD+Route**
Mean	207.5	236.1	248.8	271.9
Standard Deviation	54.6	56.0	48.8	61.0
N	21	21	21	21

Table 14. Pairwise comparisons of departure NWS PSD by condition (α = .05, HSD = 44.88)

	Data Comm / Paper	**Data Comm / MMD**	**Data Comm / MMD+Route**
Voice / Paper	28.6	41.3	64.5 *
Data Comm / Paper		12.7	35.8
Data Comm / MMD			23.2

NOTE: statistical significance indicated by *

NWS PSD analysis by day effect:

Table 15 shows mean and standard deviation for NWS PSD for all conditions and phases of flight, by day (i.e., which day of the experiment the event occurred) to investigate training effects. Results of the Analysis of Variance (ANOVA) indicated no significant difference (F(1,166)=2.2, p=0.14), between the two days of the experiment (for each crew).

Table 15. NWS PSD for all scenarios by day

	Day 1	**Day 2**
Mean	217.1	201.9
Standard Deviation	71.1	61.1
N	80	88

NWS PSD analysis by phase of flight:

Table 16 shows mean and standard deviation for NWS PSD for all conditions and test days, by phase of flight. Results of the ANOVA indicated a significant difference (F(1,166)=50.62, p<0.0001), between arrival and departure scenarios, supporting the discussion above concerning increases in NWS activity because there are more turns required, by design, for the departure than for the arrival taxi tasks. This is additional analysis requested by the FAA.

Table 16. NWS PSD by phase of flight

	Arrivals	Departures
Mean	177.2	241.1
Standard Deviation	57.3	59.1
N	84	84

4.2.2 Taxi Speed

Figure 20 shows taxi speed during Arrival and Departure Scenarios, with respect to communications modality and display methodology (data by crew in Appendix M). Table 17contains the mean and standard deviation of taxi speed, and Table 18 the paired mean differences by condition. The analysis indicated a significant effect (F(3,80)=10.01, p<0.0001), (α=0.05, HSD=2.35, p<0.05) for Voice/Paper and Data Comm/Paper, Voice/Paper and Data Comm/MMD+Route, and Data Comm/MMD and Data Comm/MMD+Route.

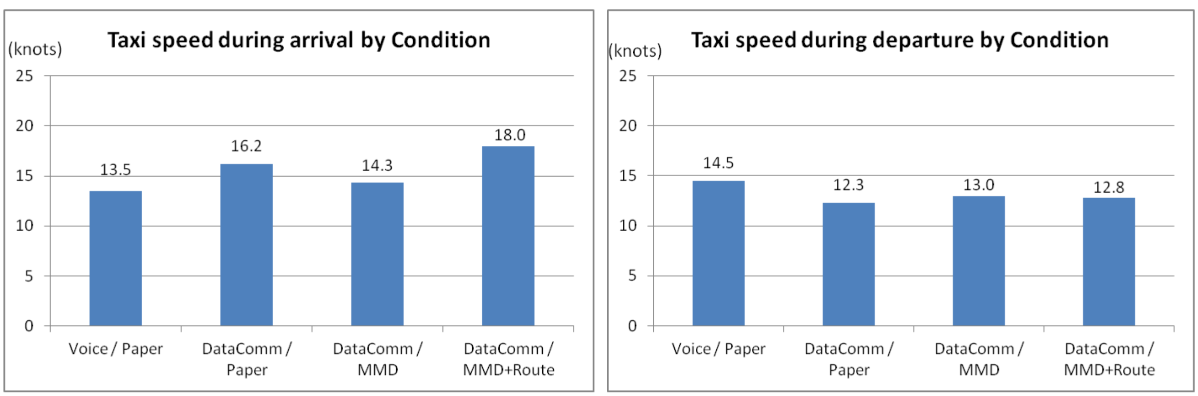


Figure 20. Taxi speed during arrival (left) and departure (right) by condition

Table 17. Mean arrival taxi speed and standard deviation by condition

	Voice / Paper	DataComm / Paper	DataComm / MMD	DataComm / MMD+Route
Mean (knots)	13.5	16.2	14.3	18.0
Standard Deviation	1.9	2.0	2.0	4.7
N	21	21	21	21

Table 18. Pairwise comparisons arrival taxi speed by condition (α=0.05, HSD=2.35)

	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Voice / Paper (knots)	2.7 *	0.8	4.5 *
Data Comm / Paper		1.8	1.8
Data Comm / MMD			3.7 *

NOTE: statistical significance indicated by *

Table 19 shows mean and standard deviation, and Table 20 shows the mean differences for departure taxi speed by condition. The analysis indicated a significant effect (F(3,80)=11.6, $p<0.0001$), ($\alpha=0.05$, HSD=1.05, $p<0.05$), for Voice/Paper and any of the other conditions.

Table 19. Mean departure taxi speed and standard deviation by condition

	Voice / Paper	DataComm / Paper	DataComm / MMD	DataComm / MMD+Route
Mean (knots)	14.5	12.3	13.0	12.8
Standard Deviation	1.8	1.1	0.8	1.2
N	21	21	21	21

Table 20. Pairwise comparisons of departure taxi speed by condition (α=0.05, HSD=1.05)

	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Voice / Paper (knots)	2.2 *	1.5 *	1.7 *
Data Comm / Paper		0.7	0.6
Data Comm / MMD			0.1

NOTE: statistical significance indicated by *

For arrivals, the results show a slight (2 knot) but significant increase in taxi speed with Data Comm modality over that in Voice modality. For departures, the results show a slight (2 knot) but significant decrease in average taxi speed of DataComm/MMD+Route over Voice/Paper. The increase in taxi speed on arrivals may be due to increased situation awareness for the PF when routes were presented more clearly in those scenarios, where shorter and simpler routes required less attention to turns than in departure scenarios. Though overall taxi speeds were higher for arrivals (Mean=15.5 knots, SD=3.3 knots) than departures (Mean=13.2 knots, SD=1.5 knots), it is important to realize that arrival scenario data analysis began at 30 knots, there were no active runway holds, there were fewer turns, taxi times were shorter, and scenario was terminated with the aircraft still moving.

4.3 Head Tracking

Some variability in head and eye tracking behavior existed across subjects during data collection. The main factor in variance was due to some pilots requiring the use of reading glasses as pilots tended to wear them low on the bridge of their nose to look over them when focusing outside the flight deck. This behavior often reversed the head up/head down pitch behavior when compared to pilots not wearing glasses in this manner, with pilots wearing reading glasses pitch their head down to look out the window. Although the use of glasses was discouraged in the attempt to maintain data integrity, pilots were still allowed to perform the tasks as they would in real world operations. If eye tracking data was available, there was no impact as the gaze vector was true regardless of head pitch angle. However, if only head tracking was available the impact of wearing reading glasses had to be accounted for. (Note: analysis of eye tracking data collected showed the software was able to maintain track when pilots transitioned between cockpit instruments and looking out the window.)

4.3.1 Head Up Aggregate Results

Aggregate head tracking analysis (Table 21 and Table 22) indicated that the overall effect observed was a statistically insignificant decrease in the PF head up time in scenarios involving Data Comm, with significant difference across conditions for the PM ($F(1,3)=4.03$, $p=0.008$). For head tracking data, differences in the 'N' value is due to some data not being usable (lost calibration, interference from glasses, etc.). [Note: data tables in Section 4.3 have a slightly different format than in Section 4.1 and 4.2 due to different approaches to calculating pairwise comparisons. In this section, $\alpha=0.05$ is used and the *p* value is only listed if it is significant.]

It is postulated that the increased requirement for the PM to interface with Data Comm messages in these scenarios using a CDU mounted in a relatively low location in the cockpit reduced the capacity for frequent lookout tasks. Display methodology conditions showed a small magnitude effect on pilot head up time, with no greater than 10% variance across the means for each crew role. Further research should be conducted to test display methodology conditions combined with Voice and not simply Data Comm in order to remove the effect of the Data Comm head up time impact.

Table 21. Aggregate head up time and standard deviation for PF and PM by condition

PF	Voice / Paper	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD + Route
Mean (percent)	47.076	45.193	42.622	41.434
Standard Deviation	26.751	23.465	23.062	22.558
N	40	41	35	40
PM				
Mean	41.152	33.388	31.861	34.267
Standard Deviation	17.126	13.622	10.883	14.46
N	42	42	40	39

Table 22. Pairwise comparisons of aggregate head up time by condition

PF	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD+Route**
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant
PM			
Voice / Paper	Not significant	*p*=0.0187	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

Whether or not a decrease in head up time is acceptable may depend on the phase of flight and associated task loading during which the decrease is observed. In-flight, head tracking analysis indicated that regardless of condition pilots focused a majority of their attention inside the cockpit. The PF spent less time head up than the PM in flight since the use of the auto-pilot was not allowed, however during surface operations, the PM spent less time head up than the PF due to cockpit tasks involved with running checklists, programming the flight management computer, and answering Data Comm messages. When the pilots' attention is required outside the flight deck, such as during taxi, head tracking analysis observed the greatest variation across modalities and crew role. Of note, crew qualitative data presented in Appendix N indicated that the decrease in head up time associated with Data Comm employment was not unacceptable.

Figure 21 shows the percentage of time the PF and PM were head up by arrival altitude bands, arrival taxi, and departure taxi (the complete data by crew is available in Appendix N). These results stand in sharp contrast to the recommendation given in Section 8-1-6(c) of the Aeronautical Information Manual. [36] The paragraph titled "Scanning for Other Aircraft" states ⅔ to ¾ of the pilot's scan should be outside the aircraft, whereas this experiment showed current commercial pilots operating in busy terminal airspace scanned outside the cockpit approximately 10% of the time while hand-flying the aircraft, and approximately 50% outside the cockpit while operating on the surface.

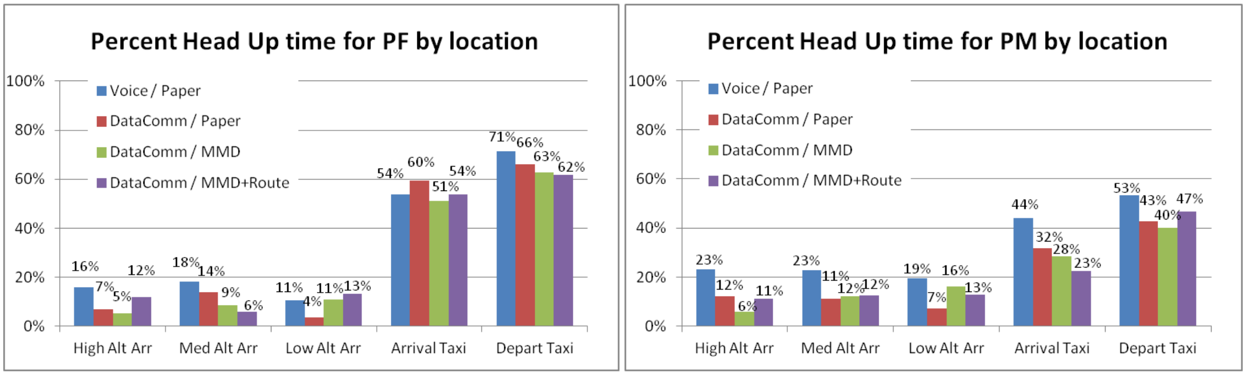


Figure 21. Percent head up time for PF (left) and PM (right) by location

4.3.2 Head Up Time By Altitude Bands

The FAA specifically requested flight crew head up data be analyzed in terms of altitude, which this section addresses. Figure 22 presents a summary of PF and PM head up time, as a function of altitude band and scenario condition. Following this data, the results are presented for each altitude band are presented (High: 16,000 – 14,000 MSL; Medium: 10,000 – 8,000 MSL; Low 7,000 – 5,000 MSL).

A statistical analysis of the head up percentage (%) in the high altitude band (Table 23 and Table 24) indicated a significant condition effect, $F(1,3)=8.10$, $p<0.001$. The Tukey HSD pairwise comparison tests indicated a significantly lower head up percentage with the Data Comm/Paper condition than the Voice/Paper diagram condition ($T=-2.826$, $p=0.0303$) for the PF. The remaining head up percentages by display methodology did not differ significantly for the PF. The HSD pairwise comparison tests for the PM indicated a significantly higher head up time in the Voice/Paper condition than the Data Comm/MMD ($T=-3.888$, $p=0.0012$) and the Data Comm/MMD+Route ($T=-2.644$, $p=0.0447$). No statistically significant difference in head up time was found to exist between crew members nor was a statistically significant interaction found to exist between crew member and condition.

Results in the high altitude band indicated that there was a statistically significant change in pilot head up behavior in the high altitude Data Comm scenarios. The Voice/Paper condition showed significantly higher head up percentage than the Data Comm/paper condition, suggesting that the effect was due to the Data Comm. No significant difference within the Data Comm conditions across display methodologies was observed.

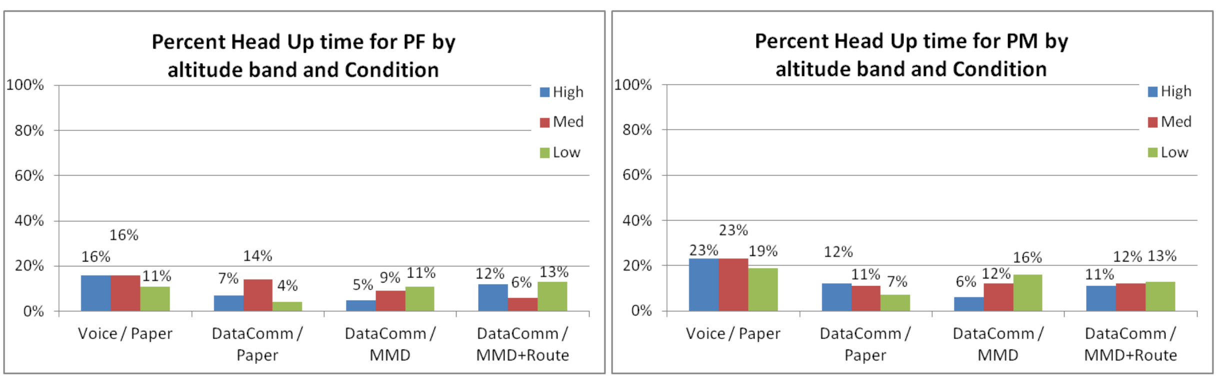


Figure 22. Percent head up time for PF (left) and PM (right) by altitude band and condition

Table 23. Head up time for PF and PM in high altitude band by condition

PF	**Voice / Paper**	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD + Route**
Mean (percent)	15.788	6.849	5.443	11.931
Standard Deviation	13.472	7.905	4.504	14.565
N	20	20	17	20
PM				
Mean (percent)	23.047	12.273	5.659	11.222
Standard Deviation	16.13	16.047	9.042	14.641
N	21	21	20	20

Table 24. Pairwise comparisons of High altitude band head up time by condition

PF	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD+Route**
Voice / Paper (percent)	Not significant	*p*=0.0303	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant
PM			
Voice / Paper	Not significant	*p*=0.0012	*p*=0.0477
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

Table 25 and Table 26 list head up time for scenarios with Data Comm messages presented in the medium altitude band. Tukey HSD pairwise comparison tests indicated no statistically significant differences between the Voice/Paper and Data Comm/Paper communication modalities or across any of the three display methodologies. No statistically significant difference in head up time was found to exist between crew members nor was a statistically significant interaction found to exist between crew member and condition.

Table 25. Head up time for PF and PM in medium altitude band by condition

PF	**Voice / Paper**	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD + Route**
Mean (percent)	16.18	13.763	8.556	6.012
Standard Deviation	18.852	12.929	13.327	7.424
N	20	20	17	20
PM				
Mean (percent)	22.849	11.093	12.139	12.443
Standard Deviation	19.11	11.797	14.929	15.707
N	21	21	20	20

Table 26. Pairwise comparisons of medium altitude band head up time by condition

PF	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD+Route**
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant
PM			
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

A statistical analysis of the head up percentage in the low altitude band (Table 27 and Table 28) indicated a significant condition effect $F(1,3)=4.46$, $p=0.005$. Tukey pairwise comparison tests indicated the Data Comm/MMD+Route condition had significantly greater head up time than the Data Comm/Paper ($T=2.740$, $p=0.0378$) for the PF, and the Voice/Paper condition had significantly greater head up time than the Data Comm/Paper condition (*T*=-2.732, *p*=0.0382). Statistical analysis indicated a significant crew role effect, indicating the PM showed greater head up than the PF $F(1,3) = 4.09$, $p = 0.045$.

Results for the low altitude band suggest that both the communication modality and display methodology had a significant effect on the percentage of PF head up time. Data Comm/MMD and Data Comm/MMD+Route were both associated with significantly more eyes-out when compared to the Data Comm/Paper condition, but not with each other. This suggests that the MMD and MMD+Route displays allow the PF's attention to be out the window more than the Data Comm/Paper condition. There was also a significant difference between Data Comm/Paper and Voice/Paper conditions. Data Comm/Paper had a significantly lower head up percentage than all other three conditions. This is partially explained by pilots having to have attention inside the flight deck to locate the paper maps and prepare for expected taxi accordingly, which may not have been as necessary with the MMD conditions.

Table 27. Head up time for PF and PM in low altitude band by condition

PF	**Voice / Paper**	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD + Route**
Mean (percent)	10.568	3.553	11.044	13.44
Standard Deviation	11.691	4.739	15.687	11.562
N	20	20	17	20
PM				
Mean (percent)	19.377	7.189	16.189	12.662
Standard Deviation	17.521	11.42	13.729	14.464
N	21	21	20	20

Table 28. Pairwise comparisons of low altitude band head up time by condition

PF	**Data Comm / Paper**	**Data Comm / MMD**	**Data Comm / MMD+Route**
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	*p*=0.0378
Data Comm / MMD			Not significant
PM			
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

In general, during inflight arrival conditions, a finding of significant difference between communication modality suggests that the introduction of the Data Comm drives pilots' attention inside the cockpit reducing their head up time. In the low altitude band, the display methodology impacted the head up percentage, combined with significance existing between crew role suggesting the introduction of a MMD or MMD+Route allows pilots to spend more time head up. This difference in crew role is largely explained by the crew role responsibility differences during this phase of flight. As the aircraft approaches the runway, the PF will bring his/her attention out the window, relying less on instruments. This is especially true in daytime VMC, the weather condition for all scenarios in this experiment. However, this behavior was not observed in the head tracking results when contrasted to head up percentages of the other in-flight altitude bands. This change in behavior may be due to the PF hand flying the aircraft and spending significant time monitoring the PFD glide slope and course deviation markers that become increasingly difficult to track as the aircraft closes in on the runway, keeping his attention inside the flight deck. The PM also spends a slightly increased amount of time head up compared to the PF during this phase, sharing time on the instruments to make call-outs to the PF.

4.3.3 Head up Time During Taxi Operations

As in Section 4.2, the FAA also requested additional data analysis of head up time during taxi or surface operations as a function of arrival and departure scenarios. Statistical analysis comparing the variance between arrival and departure taxi scenarios indicated the departure taxi scenario yielded significantly greater head up time than the arrival taxi scenario, $F(1,3)= 2.09$, $p<0.001$. No significance was found in the interaction of arrival or departure conditions, suggesting that conditions varied similarly for both arrival taxi and departure taxi. Figure 23 summarizes the findings.

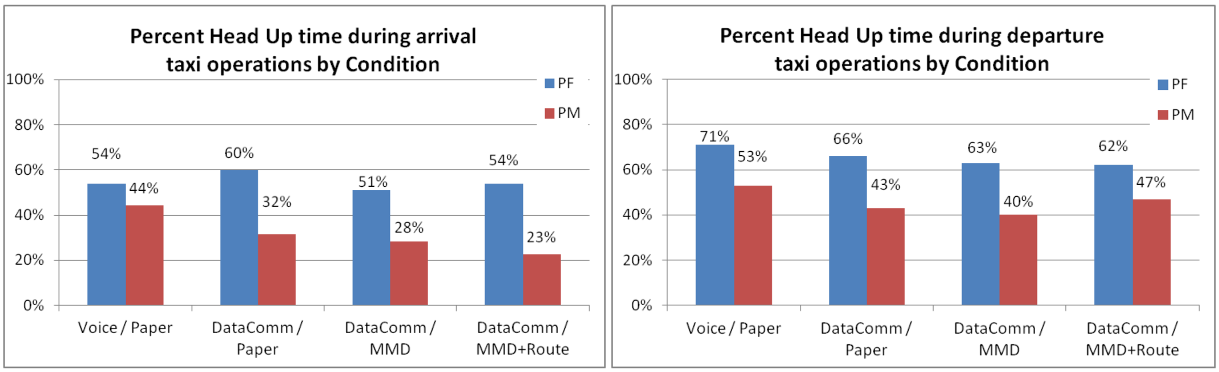


Figure 23. Percent head up time during arrival (left) and departure (right) taxi operations

As shown in Table 29 and Table 30, a statistical analysis of the head up percentage in the arrival taxi scenarios indicated a significant condition effect, $F(1,3)=4.47$, $p=0.005$. There were no significant differences across conditions for the PF. There was significantly greater head up time in the Voice/Paper condition than the Data Comm/Paper condition ($T=-3.144$, $p=0.0125$), greater head up time in the Voice/Paper than the Data Comm/MMD ($T=-3.867$, $p=0.013$), and greater head up time in the Voice/Paper than the Data Comm/MMD+Route ($T=-5.278$, $p<0.0001$) for the PM. There was statistical significance between crew role, $F(1,3)=89.89$, $p<0.001$, and significant interaction between crew role and condition, $F(1,3)=4.16$, $p=0.007$.

Table 29. Head up time for PF and PM during arrival taxi operations by condition

PF	Voice / Paper	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Mean (percent)	53.717	59.517	51.008	53.864
Standard Deviation	20.374	14.677	12.68	17.591
N	20	20	16	19
PM				
Mean (percent)	44.272	31.627	28.315	22.491
Standard Deviation	14.945	12.948	10.871	12.826
N	21	21	19	19

Table 30. Pairwise comparisons of arrival taxi head up time by condition

PF	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Voice / Paper (percent)	Not significant	Not significant	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant
PM			
Voice / Paper (percent)	p=0.0125	p=0.0013	p<0.0001
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

Analysis of the arrival taxi phase represents the pilots' behavior from rollout (below 80 knots) to the end of the run. Comparison tests indicated a significant difference between Voice and Data Comm coupled with a display methodology. This effect was pronounced in the case of the PM, with little variance existing across conditions for the PF. The PM with Data Comm/MMD+Route condition indicated significantly lower head up time compared to the PM with Voice/Paper condition, suggesting not only did the Data Comm decrease head up time, but Data Comm combined with any display methodology did as well. This effect was only observed with the PM.

Statistical significance between crew role and the interaction of crew role and scenario condition indicated a difference in crew behavior between the PF and PM that is dependent on the communications modality and display methodology. The taxi phase of arrival scenarios was considerably shorter than the departures phase (2-3 minutes versus about 15 minutes). It is postulated that the faster pace of the taxi portion of arrival scenarios necessitated a tactical focus on the part of the PF, with the primary task being recognition and execution of upcoming turns requiring their attention out the window increasing their head up time. This requirement remained essentially unchanged across conditions, as SA was essentially provided entirely verbally by the other crew member, rather than by displays or messages. The PM had to assume more of a strategic role (interpreting the rapidly changing clearances and providing directive commentary to the PF), driving their attention inside the flight deck. The presence of Data Comm and the low location of the CDU interface exacerbated the effect of decreased head up time for the PM on the arrival taxi.

A statistical analysis of the head up percentage in the departure taxi scenario indicated a significant condition effect, F(1,3)=11.08, p<0.001 (Table 31 and Table 32). Tukey pairwise comparison tests indicated significantly more head up in the Voice/Paper condition compared to the Data Comm/MMD condition, (T=-3.346, p=0.0069) and (T=-4.341, p=0.0003) for the PF and PM respectively. There was significantly more head up time with the Voice/ Paper condition than the Data Comm/ Paper condition (T=-3.506, p=0.0042) for the PM. Also observed was significantly more head up time with the Voice/Paper condition than the Data Comm/MMD+Route condition (T=-3.809, p=0.0016) for the PF. The remaining head up percentages by condition did not differ significantly. There was statistical significance between crew role, F(1,3)=195.70, p<0.001. No statistically significance difference was found in the interaction between crew role and condition.

Table 31. Head up time for PF and PM during departure taxi operations by condition

PF	Voice / Paper	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Mean (percent)	71.281	66.094	62.607	61.668
Standard Deviation	9.196	7.665	7.099	7.738
N	20	21	18	20
PM				
Mean (percent)	53.175	42.577	39.89	46.759
Standard Deviation	12.307	11.106	6.72	7.574
N	21	21	20	19

Table 32. Pairwise comparisons of departure taxi head up time by condition

PF	Data Comm / Paper	Data Comm / MMD	Data Comm / MMD+Route
Voice / Paper (percent)	Not significant	p=0.0069	p=0.0016
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant
PM			
Voice / Paper (percent)	p=0.0042	p=0.0003	Not significant
Data Comm / Paper		Not significant	Not significant
Data Comm / MMD			Not significant

In departures, the presence of Data Comm decreased the head up percentage relative to the Voice communication condition, significantly so for the PM. No significant difference in Data Comm conditions was observed across display methodology, suggesting pilot behavior was not significantly affected by ownship being presented on the head down displays versus the use of a paper map. Significance between crew role but not the interaction of crew role and condition indicates that there was a similar behavior change across conditions for each pilot, with variance in head up percentage being derived from differences in crew tasks during the departure taxi phase. In contrast to the arrival scenarios, departure scenarios afforded more time for decision making for both crew members, and allowed the PF to assume a more strategic role. Thus, the method of information delivery had a greater effect on head up time for this crew role. The decreased pace of decisions also afforded greater head up time for both crew members in these scenarios.

4.4 Post-Scenario Questionnaire Results

Section 4.4 presents a summary of results from the questionnaires. Complete data from the Post-Scenario Questionnaires is in Appendix O, and from the Post-Experiment Questionnaire in Appendix P. For the Post-Scenario Questionnaire, workload and situation awareness (SA) responses were categorized into ‘inflight’ (when the aircraft was airborne, and occurred only during arrival scenarios), and ‘surface’ (aircraft movement on the ground, occurred in both arrival and departure scenarios).

4.4.1 Post-Scenario Ratings on Workload

Subjects used Bedford scale to rate the workload associated with inflight and surface operations. Full results are in Appendix O, Section O.1. Figure 24 presents results from post-scenario questionnaires regarding workload, and indicates a perception of relatively low workload for all conditions (both inflight and surface operations). Along the x-axis, a rating of 1 indicates “workload insignificant”, 5 “reduced spare capacity”, and 10 “task abandoned” (the higher count for ‘Surface’ is due to that operation occurring in both arrival and departures scenarios.)

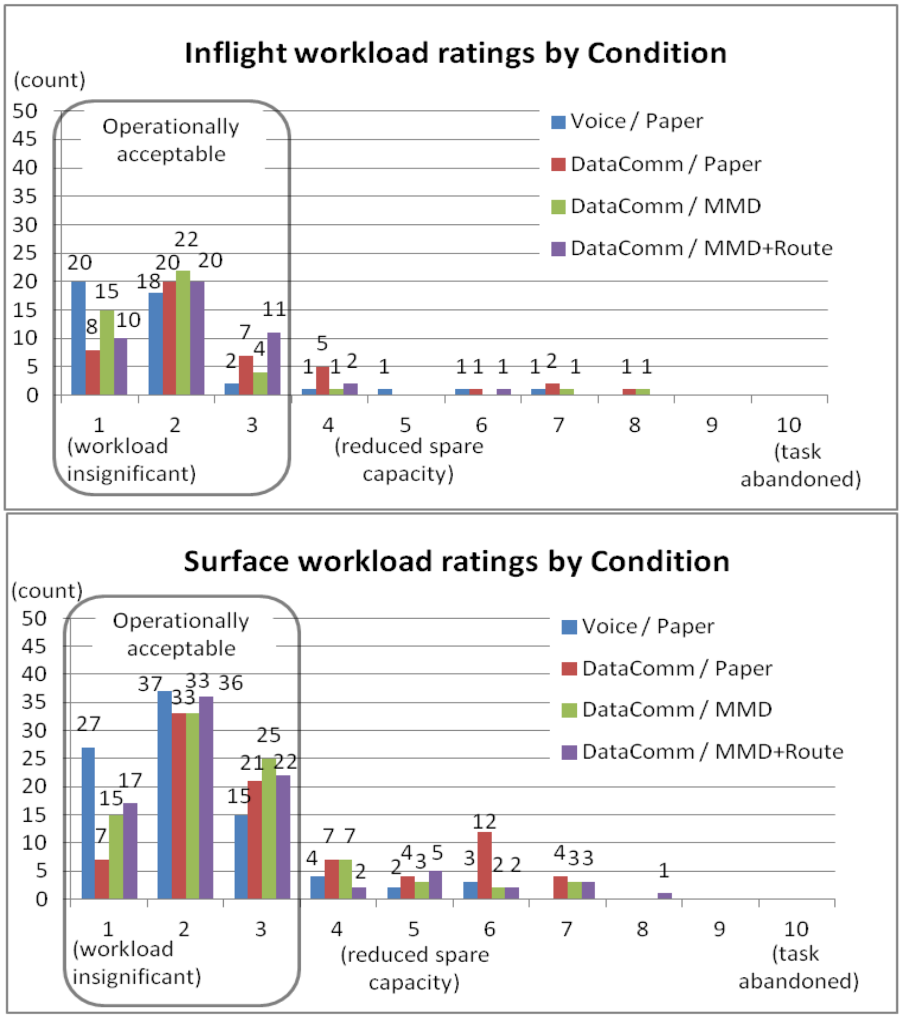


Figure 24. Inflight (top) and Surface (bottom) workload ratings by condition

PF ratings of workload in flight operations (Table 46 and Table 48) during arrivals were significantly higher than PM ($\chi^2(1)$=9.094, p= 0.003), but were not for surface operations (Table 47 and Table 48) during arrivals and departures ($\chi^2(1)$ =2.339, p=0.126). A binomial test with a cutpoint of 3 (“Enough spare capacity for all desirable additional tasks”) and test proportion of 75% showed that most ratings were significantly on the low workload side of the scale for both PFs and PMs, for inflight and surface operations (Table 49). For inflight operations, over 84% of PF ratings and over 94% of PM ratings were 3 or less; and of the 88 rating opportunities, PF rated workload at 7 (“Very little spare capacity, but maintenance of main task not in question”) or greater in only 5 case and PM only once. For surface operations, over 78% of PF ratings and over 85% of PM ratings were 3 or less; and of the 176 rating opportunities, PF ratings were 7 or more in only 6 cases, and for PMs only in 5 cases.

Figure 25 shows the median responses for PF and PM workload ratings for flight portions of the arrival scenarios. Both PF and PM rated mean workload significantly different during flight operations

(Table 51 and Table 52) among the display conditions (PF: $\chi^2(3)=28.525$, $p<0.001$, PM: $\chi^2(3)=25.245$, $p<0.001$). While medians appear fairly constant, pairwise Wilcoxon Signed Rank tests (Bonferroni adjusted $\alpha=0.05$, whereby significance is $p<0.008$) show that PF rated workload in flight operations with the DataComm/Paper condition as significantly different than any other condition (Table 51, Table 52, and Table 54). Mean ranks suggest that the DataComm/Paper ratings are higher (Table 46 and Table 54). PM rated workload for flight operations as significantly different between Voice/Paper and both DataComm/Paper and DataComm/Route; where Voice/Paper mean ranks are lower than either of these other conditions. PM ratings for inflight workload for the DataComm/Route condition were not only significantly higher than those for Voice/Paper, but also for DataComm/MMD. The DataComm/Paper condition was significantly different from (and had higher average workload ratings than) both the Voice/Paper, and the DataComm/MMD conditions.

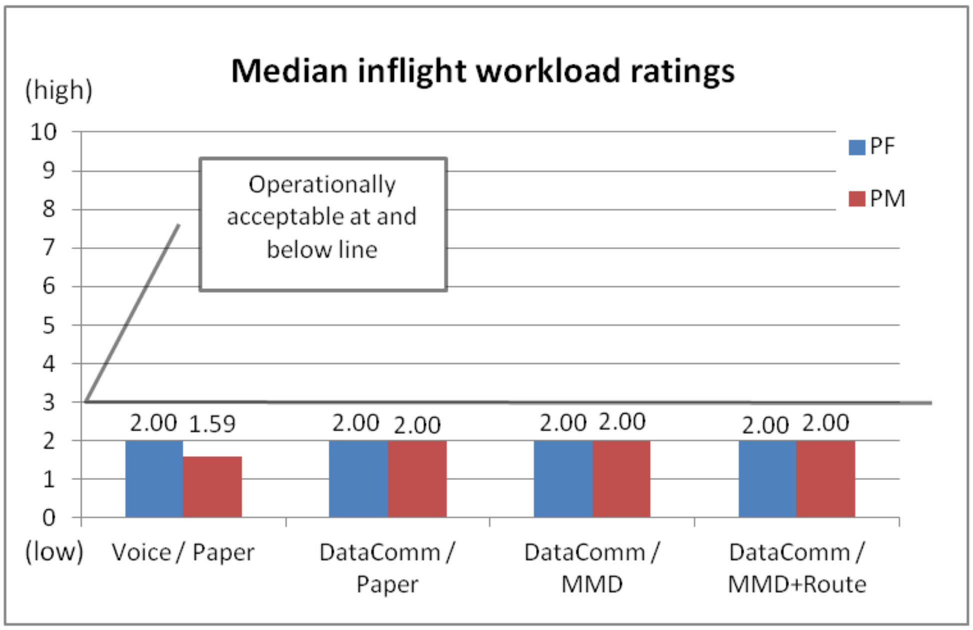


Figure 25. Inflight workload ratings by position and by condition

Figure 26 shows the median responses for PF and PM workload ratings for surface (taxi) operations occurring in both arrival and departure scenarios. Both PF and PM rated workload (Table 51 and Table 55) during surface taxi operations significantly different among display conditions (PF: $\chi^2 2(3)=43.603$, $p<0.001$; PM: χ^2 $(3)=34.875$, $p<0.001$). Post-hoc comparisons show the same patterns as that of inflight ratings (Table 51and Table 54). For PF, the DataComm/Paper condition appeared to have significantly higher ratings than all other conditions. PM rated workload for flight operations as significantly different between Voice/Paper and both DataComm/Paper and DataComm/Route; where Voice/Paper mean ranks are lower than either of these other conditions (Table 46 and Table 54). PM ratings for inflight workload for the DataComm/Route condition were not only significantly higher than those for Voice/Paper, but also for DataComm/MMD. The DataComm/Paper condition was significantly different from (and had higher average workload ratings than) both the Voice/Paper, and the DataComm/MMD conditions. With PF and PM ratings combined, there were no significant differences in workload among display condition for any of the tested altitude bands in either arrival or departure operations (Table 58 and Table 59).

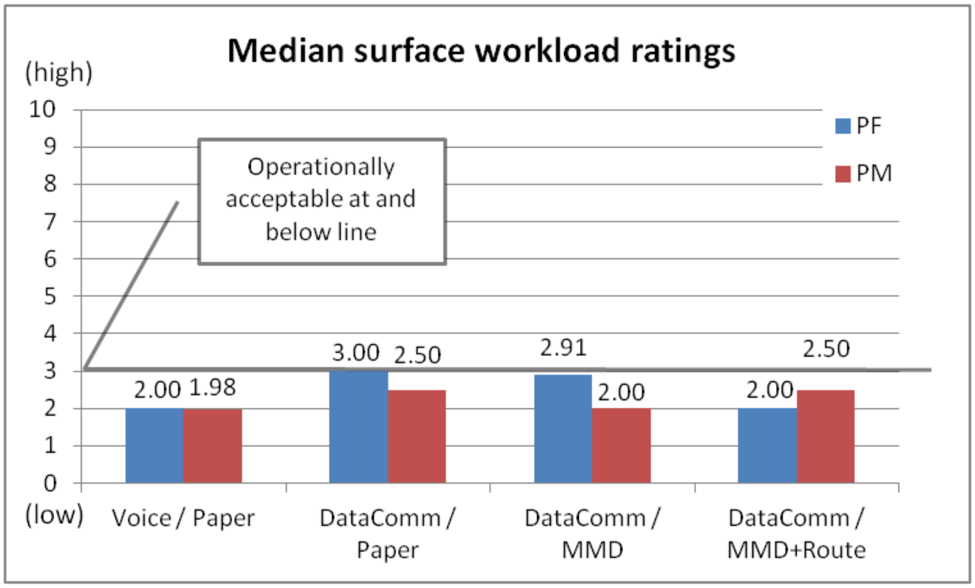


Figure 26. Surface workload rating by position and by condition

Regardless of the scenario segment, display condition, or role of the respondent, workload ratings were rarely extreme. The PF experienced higher workload in the flying portions of the arrival scenarios than did the PM. While the patterns differed, depending on whether the rater was PF or PM, the pattern for each type of crew member's ratings as affected by display conditions was the same for in flight and surface operations. For PF, in all cases, workload was rated highest for the DataComm/Paper condition; but interestingly, there were no significant differences between the Voice/Paper condition and when DataComm was augmented with the MMD, and Route. For PM, the Voice/Paper condition appeared to induce lower workload than either the DataComm/Paper or the DataComm/Route conditions, but did not significantly differ from the DataComm/MMD condition. The DataComm/MMD condition was also rated as having lower workload than either the DataComm/Paper or DataComm/Route conditions. Regardless of operation or crew role, the Voice/Paper and the DataComm/MMD conditions are never associated with significantly greater workload conditions than the DataComm/Paper and DataComm/Route conditions, and the DataComm/MMD condition was associated with the lowest workload ratings of all the DataComm conditions for PM.

4.4.2 Post-Scenario Ratings on Situation Awareness

SA scores were obtained for both the inflight and surface/taxi operations of the scenarios (inflight assessments were only available for arrivals). Full results are in Appendix O, Section O.2. The SART technique results in a score that can range from 13 (highest SA) to -5 (lowest SA). SART ratings were collected for inflight operations (only during arrival scenarios), arrival surface operations only, and departure surface operations only. Binomial tests were conducted for both PF and PM, and results indicate that the preponderance of the data for both pilot roles and for each SART measure favored the high end of the scale, demonstrating high SA on the whole.

PF and PM SART ratings significantly differed for inflight scenario segments ($\chi^2(1)=16.341$, $p<0.001$) (Figure 27), surface/taxi operations in arrival scenarios ($\chi^2(1)=4.450$, $p=0.035$) (Figure 28), but not surface/taxi operations in departure scenarios ($\chi^2(1)=0.872$, $p=0.351$) (Figure 29). Both PF ($\chi^2(1)=10.342$, $p=0.016$) and PM ($\chi^2(1)=15.459$, $p=0.001$) SART scores significantly differed by condition for surface/taxi operations during arrival scenarios. Dunnett's C statistics indicate that for PF, the scenarios with a Voice/Paper condition had ratings that were significantly higher than scenarios with the Data Comm/Paper condition. For PMs, the ratings for the Voice/Paper condition were higher than all Data Comm conditions. Analysis across all conditions did not differentially affect SART ratings for the flight segments for either PF ($\chi^2(1)=2.723$, $p=0.436$) or PM ($\chi^2(1)=5.205$, $p=0.157$), or for the surface/taxi operations in departure scenarios (PF: $\chi^2(3)=2.982$, $p=0.394$; PM: $\chi^2(3)=1.875$, $p=0.599$).

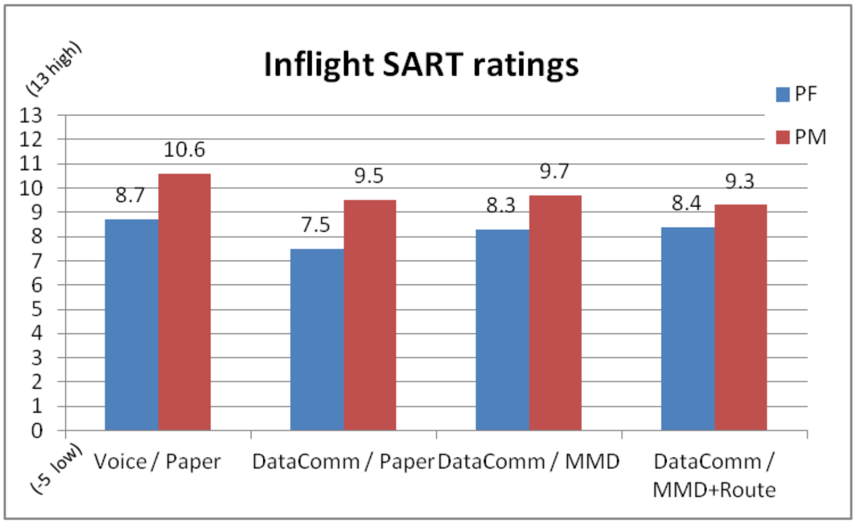


Figure 27. SART ratings for inflight operations by condition

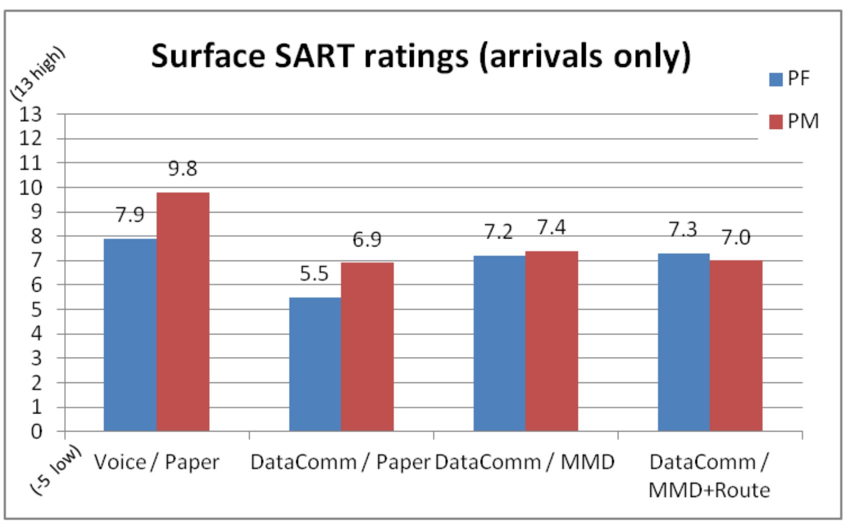


Figure 28. SART ratings for only surface arrival operations by condition

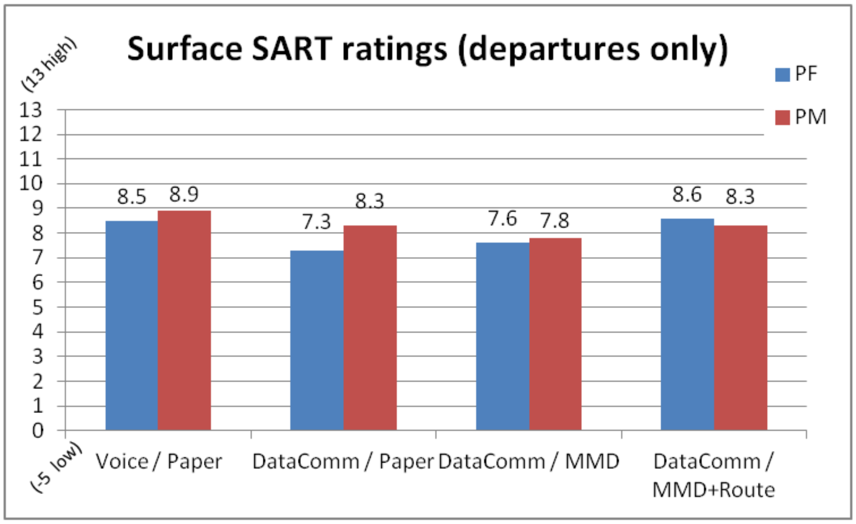


Figure 29. SART ratings for only surface departure operations by condition

In summary, results from the post-scenario questionnaire indicate reduced SA due to Data Comm. During surface/taxi operations in arrival scenarios, PMs experienced significantly higher SA when using the Voice/Paper condition than any other Data Comm condition. PFs showed the same SA reduction from Voice/Paper only over the Data Comm/Paper. During departure, SA differences were not shown. However, post-test debriefing comments seem to indicate that the crews still considered the SA acceptable regardless of communication modality, display methodology, or the altitude at which Data Comm messages were given to the crew. SA scores were generally high, and PM rated SA higher during flight operations and during surface/taxi operations in arrival scenarios than PF. Experimental conditions did not differentially affect SA ratings for either crew role during the flight scenario segments.

4.4.3 Post-Scenario Ratings on Acceptability

Appendix D, Section D.5 contains the nine questions on the post-scenario survey that addressed the acceptability of different aspects of the conditions, and some of these were only relevant for some conditions. The rating scale for all nine questions was weighted so that 1 represented an improvement or very high acceptability, a 4 represented acceptable or no change to current operations, and a 7 represented an operationally unacceptable or unsafe condition. Full results are in Appendix O, Section O.3.

Question 1: Did the display of the OWNSHIP POSITION on the navigation display make the taxi clearance easier to understand and to carry out? (1 – easier to understand, 7 – not easier to understand)

Mean and Standard Deviation values are listed in Table 69, differences by crew position in Table 78, differences by Condition in Table 79, and the Binomial Test in Table 88. Both PFs and PMs overwhelmingly stated displaying the ownship position on the ND made taxi clearances easier to understand and carry out. This question was only relevant for the Data Comm/MMD and Data Comm/MMD+Route conditions.

Question 2: Did the display of the ROUTE on the navigation display make the taxi clearance easier to understand and to carry out? (1 – easier to understand, 7 – not easier to understand)

Mean and Standard Deviation values are listed in Table 70, differences by crew position in Table 78, differences by Condition in Table 79, and the Binomial Test in Table 88. Both PFs and PMs overwhelmingly stated display of route on the ND made taxi clearances easier to understand and carry out ($\chi^2(1) = 0.058$, $p = 0.809$).

(Note: Question 3 was analyzed with #9; please see the end of this Section.)

Question 4: Did you have a sufficient amount of time to respond to the Voice or Data Comm transmitted messages? (1 – more than enough time, 7 – not enough time)

Mean and Standard Deviation values are listed in Table 72, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 80, by altitude band in Table 86, and the Binomial Test in Table 88. PF ratings were significantly worse than PM ratings when asked whether they had sufficient amount of time to respond to the Voice or Data Comm transmitted messages ($\chi^2(1) = 12.639$, $p < 0.001$). Both PF and PM ratings were significantly affected by display condition (PF: $\chi^2(3) = 27.635$, $p < 0.001$; PM: $\chi^2(3) = 18.974$, $p < 0.001$). Both PFs and PMs rated the Voice/Paper condition as more acceptable than any other condition. Although statistical differences were observed, the PF (mean 2.5) and PM (mean 2.1) ratings indicate that generally flight crews felt there was enough time for the flight crew to respond. Pilots always indicated there was sufficient time in the Voice/Paper condition. While the preponderance of ratings indicated sufficient time for Data Comm conditions, there were a few ratings where the pilots did not have sufficient time.

Question 5: Was the amount of head down time required to receive and respond to just the “Expected Taxi” Data Comm messages acceptable in this scenario? (1 – minimal increase in Head Down time, 7 – too much Head Down time)

Mean and Standard Deviation values are listed in Table 73, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 81, and the Binomial Test in Table 88. The PFs rated the acceptability of the head down time required to receive and respond to “Expected D-TAXI” messages significantly worse than the PMs ($\chi^2(1) = 12.159$, $p < 0.001$). Neither PFs nor PMs showed differences as a function of Data Comm condition (paper, moving map, route). Although statistical differences were observed, the PF (mean 3.1) and PM (mean 2.5) ratings indicate that operationally the amount of head down time was acceptable to the crew.

Question 6: Was the amount of head down time required to receive and respond to other non-time-critical Data Comm messages acceptable in this scenario? (1 – minimal increase in Head Down time, 7 – too much Head Down time)

Mean and Standard Deviation values are listed in Table 74, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 82, and the Binomial Test in Table 88. The PFs rated the acceptability of the head down time required to receive and respond to other non-time-critical Data Comm messages (e.g., frequency changes or new altimeter setting) significantly worse than the PMs ($\chi^2(1) = 24.162$, $p < 0.001$). Neither group showed differences as a function of Data Comm condition (paper, moving map, route) (PF: $\chi^2(2) = 1.822$, $p = 0.402$); PM: $\chi^2(2) = 0.556$, $p = 0.757$). Although statistical differences were observed, the PF (mean 3.1) and PM (mean 2.2) ratings indicate that operationally the amount of head down time was acceptable to the crew.

Question 7: Overall, was the communications mode (Voice or Data Comm) for receiving Expected Taxi and Taxi clearances acceptable during this scenario? (1 – completely acceptable, 7 – completely unacceptable) [NOTE: this question was presented to the subjects only during Data Comm scenarios]

Mean and Standard Deviation values are listed in Table 75, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 83, by altitude band in Table 86, and the Binomial Test in Table 88. Figure 30 presents a histogram of ratings regarding the acceptability of using Data Comm to receive Expected D-TAXI and D-TAXI messages. Overall results indicate high acceptability for Data Comm to be used to issue taxi route clearances. The PF (mean 2.7) and PM (mean 2.0) ratings indicate PFs rated overall acceptability of the Data Comm for receiving Expected D-TAXI and D-TAXI clearances statistically, but not operationally, significantly worse than PM ratings. However, the display conditions within the PF and PM ratings indicate no statistical significance. Pilots' ratings of Data Comm use in a busy terminal area were heavily skewed in the acceptable range of the scale. The few unacceptable ratings that occurred were predominately in the Data/Paper condition.

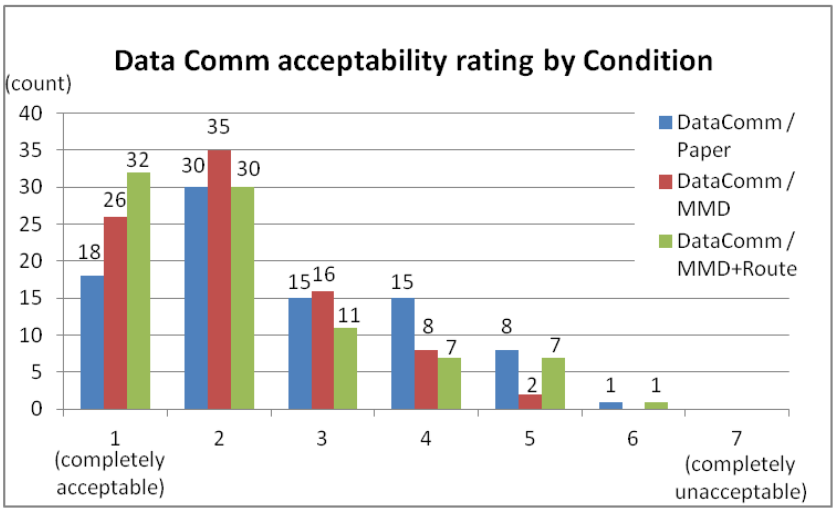


Figure 30. Data Comm acceptability rating by condition

<u>Question 8</u>: How much operational risk was introduced by the communication mode (Voice or Data Comm) used during this scenario? (1 – extremely low risk, 7 – extremely high risk)

Mean and Standard Deviation values are listed in Table 76, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 84, by altitude band in Table 86, and the Binomial Test in Table 88. Overall, the PFs rated operational risk higher than the PM, and display conditions affected both PF and PM ratings. For the PFs, ratings indicated that more operational risk was assumed when operating in the Data Comm/Paper condition than the Data Comm/MMD+Route condition, however the difference was not considered operationally significant. PM ratings did not significantly differ by display condition. Although statistical differences were observed, the PF (mean 2.8) and PM (mean 2.2) ratings indicate that operationally Data Comm is considered low risk by the crew. These post-scenario ratings were not correlated to post-experiment comments provided by the pilots, which could offer insight into why the distribution of responses varied based on condition (see chart #8 in Appendix O.3). However in the list of post-experiment comments from pilots (Section 4.6), there are several comments that indicate most pilots favored the use of Data Comm in general, with several specific instances where Data Comm should not be used. It is postulated (no analysis conducted) that many of the high operational risk ratings were due to one or two specific events within a scenario, and not meant to indicate the use of Data Comm in general.

Question 3: Did you have confidence that the taxi route was accurately depicted based on the Data Comm ATC instruction? (1 – confident the route was accurate, 7 – not confident the route was accurate)

Question 9: Was there a point at which you did not feel that the transmitted taxi instructions were accurate? (1 – the message was accurate, 7 – did not feel the message was accurate)

Mean and Standard Deviation values are listed in Tables 71 and 77, differences by crew position in Table 78, differences by Condition in Table 79, pairwise comparisons in Table 85, by altitude band in Table 86, and the Binomial Test in Table 88. PFs and PMs did not differ significantly on rating their confidence that the taxi route was accurately depicted on the ND based on the Data Comm ATC instruction. They differ on their ratings as to whether at some point the transmitted taxi instructions were not accurate. PF ratings were on average higher than PM ratings. Condition (map or route) did not significantly affect either PF or PM ratings as to whether the taxi instructions may be inaccurately presented. Although statistical differences were observed, the PF (mean 1.7) and PM (mean 1.4) ratings indicate that operationally the Data Comm messages were believed to be accurate by the crew.

In summary, the overall ratings indicated an acceptability of Data Comm by flight crews in all conditions. Where statistically significant differences for some of the acceptability questions were demonstrated across conditions, means for both PFs and PMs were well below the operationally acceptable rating on the scale (set as the mid-point of 4). PFs rated overall and several specific acceptability questions lower than PMs. In particular, PFs were less likely to indicate that there was sufficient time to respond to the message, that heads down time was appropriate, and that, overall, communication modality was acceptable and that operational risk was higher. Display conditions were distinguished only in ratings of time sufficiency, operational risk. Both PF and PM indicated that the Voice/Paper condition was most efficient in terms of time available to respond to messages, PFs found more operational risk in the Data Comm/Paper condition than the Data Comm / MMD+Route condition.

4.5 Post-Experiment Questionnaire Results

4.5.1 Post-Experiment Ratings on Workload Comparison

The first section of the post-experiment survey asked the subject pilots to compare the perceived workload of the four conditions to the other conditions. In terms of workload rating comparisons (Figure 31), the results show a preference for DataComm/Paper compared to Voice/Paper, for DataComm/MMD compared to DataComm/Paper, and for DataComm/MMD+Route compared to any other display condition. The PF and PM ratings indicate that the Voice/Paper condition was the least preferred in terms of workload, effectively rating that condition as the highest workload.

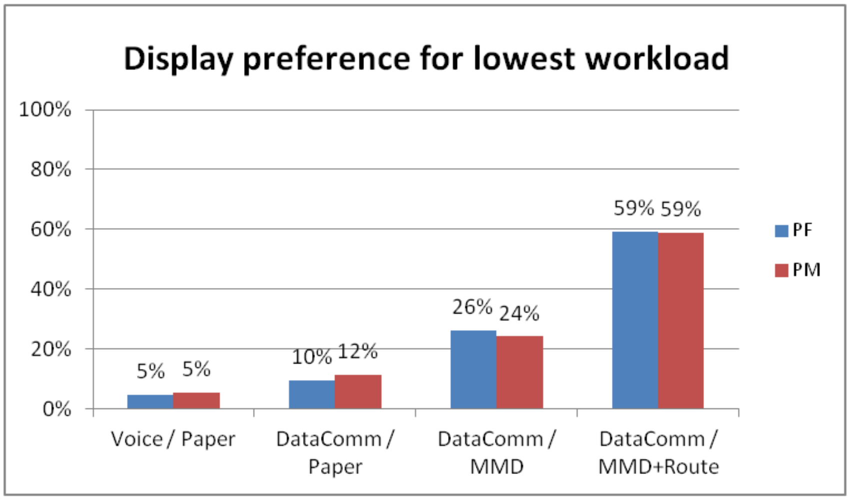


Figure 31. Display preference for lowest workload by condition

ANOVA showed no significant effect of crew role by condition interaction (F=0.379, *p*=0.768,) or main effect of crew role (F=0.030, *p*=0.862), but did indicate a significant effect of condition (F=272.309, *p*<0.001) (Table 90). Tukey HSD post-hoc comparisons among conditions revealed significant differences among all pairs (*p*≤0.001).

4.5.2 Post-Experiment Ratings on Situation Awareness Comparison

The second section on the post-experiment survey asked subject pilots to compare their perceived SA between the four conditions (Appendix E.2, results in Appendix P.2). Figure 32 shows that the results for SA mirror those for workload. In terms of SA, both the PFs and PMs considered the Voice/Paper condition to be least preferred, DataComm/Paper more preferred, and preference increased with the addition of the MMD and again with the addition of the Route.

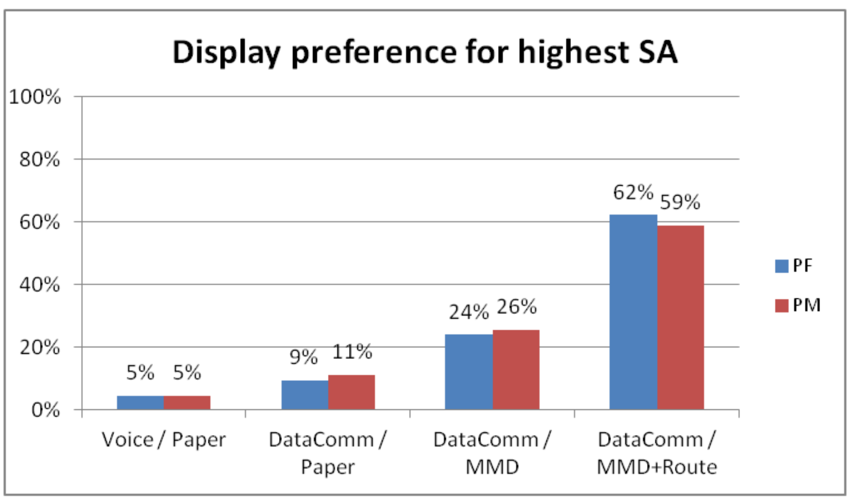


Figure 32. Display preference for highest situation awareness by condition

ANOVA showed no significant effect of crew role*condition interaction (F=1.543, p=0.210) or main effect of seat (F=0.038, p=0.847), but did indicate a significant effect of condition (F=777.067, p<0.001) (Table 96). Tukey HSD post-hoc comparisons among conditions revealed significant differences among all pairs (p≤0.001).

4.5.3 Post-Experiment Ratings on Acceptability of Expected D-TAXI Messages

The third section asked pilots to rate the acceptability of controllers sending Expected D-TAXI messages and the acceptability of flight crews responding to Expected D-TAXI messages by condition and by altitude (Appendix E.3, results in Appendix P.3). Responses to the acceptability of receiving Expected D-TAXI messages from controllers did not vary significantly by crew position (PF or PM) or by display methodology (paper, MMD, MMD+Route). On average, the 22 subject pilots responded that it was acceptable for controllers to send Data Comm messages to the flight crew in a busy terminal area with the exception of the time between the Final Approach Fix (FAF) and above 80 knots during landing roll-out. A list of the number and percentage of crews who responded it is acceptable for a controller to send Data Comm messages is as follows:

When would it be acceptable for a controller to send an Expected Taxi clearance via Data Comm?

• above 10,000 feet MSL:	22 of 22	100%
• between 10,000 feet and Final Approach Fix:	18 of 22	82%
• between FAF and below 80 knots on roll-out:	3 of 22	14%
• during taxi or surface operations:	21 of 22	95%

A parallel question was asked regarding when the flight crew thought it would be acceptable for the crew to be expected to respond to an Expected D-TAXI message. Due to a paperwork error, the first two-person crew was not asked this question. Responses to the acceptability of flight crew responding to Data Comm messages did not vary significantly by crew position or by display methodology. A list of the number and percentage of crews who responded they would respond within two minutes is as follows:

When would the flight crew respond to the Expected Taxi message within 2 minutes?

• above 10,000 feet MSL:	20 of 20	100%
• between 10,000 feet and Final Approach Fix:	12 of 20	60%
• between FAF and below 80 knots on roll-out:	1 of 20	5%
• during taxi or surface operations:	18 of 20	90%

4.5.4 Post-Experiment Ratings on Crew Coordination

The fifth section asked subject pilots to compare their perceived effective crew coordination between the four conditions (Appendix E.5, results in Appendix P.5). [Note: the fourth section pertained to Trust, and those questions and results are presented in Section 6 of this document.] Figure 33 shows preferences increase from Voice to Data Comm conditions, with increasing preference for additional display methodology (MMD and Route) with Data Comm conditions.

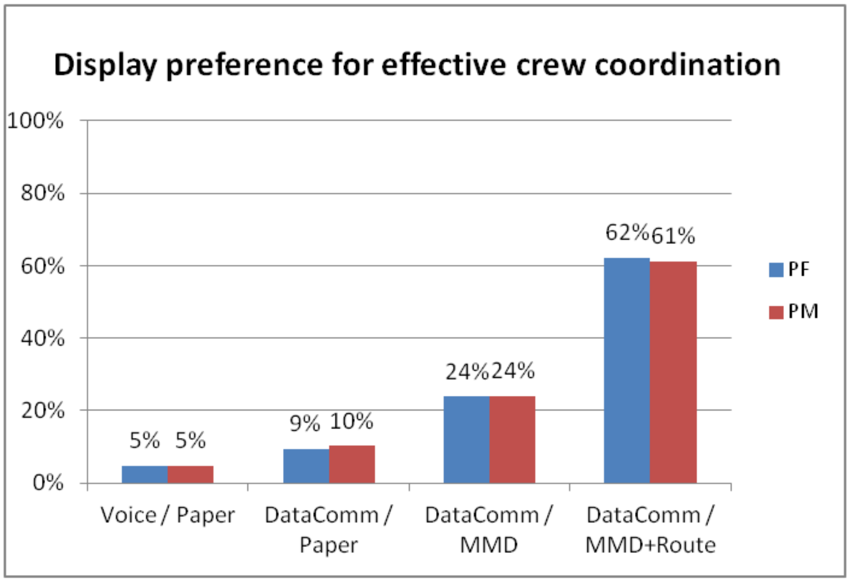


Figure 33. Display preference for effective crew coordination by condition

ANOVA showed no significant effect of crew role by condition interaction (F=0.562, p=0.642) or main effect of crew role (F=0.032, p=0.859), but did indicate a significant effect of condition (F=1915.420, p<0.001) (Table 104). Tukey HSD post-hoc comparisons revealed significant differences among all pairs ($p \leq 0.001$).

4.5.5 Post-Experiment Summary Questions

The 22 subject pilots were given the opportunity during the post-experiment questionnaire to respond to nine open-ended, free-text questions. The subject pilots were not required to answer each question, therefore, the number of respondents varies for each question. During the post-experiment verbal debrief session, these particular questions generated a lot of discussion which clarified and sometimes changed the responses, which made tabulating responses difficult. A list of the responses is given below.

<u>Question 1</u>: To what degree did the scenarios in this experiment accurately simulate a complex, high-workload environment? If not, what was missing?

- 17 of 21 respondents stated the experiment accurately simulated a complex, high-workload environment.
- Additional comments included the need to allow the use of the auto-pilot, and more radio communications during the airborne portion of the experiment scenarios.

<u>Question 2</u>: What is your overall assessment of the potential of communicating clearance updates or changes using Data Comm while an aircraft is taxiing or in busy terminal airspace?

- 18 of 22 respondents stated it was realistic to use Data Comm to issue clearances or amended clearances in a busy terminal area, either airborne or on the surface.
- Additional comments included that clearances were given too close to the new taxiway intersection, and one respondent stated the use of Data Comm was not realistic.

<u>Question 3</u>: Should the dotted cyan lines for an “Expected Taxi” clearance include red hold short bars?

- 17 of 20 respondents stated that a graphical display of an “Expected Taxi” clearance should include red hold short bars.
- 3 responded that the red hold short bars were not needed for “Expected Taxi” clearances, but were necessary for “Taxi” and “Amended Taxi” clearances.

Question 4: Will the solid magenta line for a Taxi clearance on the Navigation Display encourage crew members to begin taxiing prior to receiving the Voice message from ATC?

- 4 of 20 respondents thought the magenta line of acknowledged taxi clearance was compelling enough to cause flight crew to taxi without the required Voice instruction from ATC.
- 11 of 20 thought it might cause the crews to taxi but would be offset by training and operational procedures.
- 5 of 20 thought it would not cause the crews to taxi without the Voice instruction. This was supported by researchers who observed that many of crews initiated aircraft movement without ATC Voice instruction.
- Several pilots suggested adding “Contact ATC on xxx.xx” to the end of the Data Comm instruction (undefined number).

Question 5: Was the simultaneous Voice and Data Comm instructions to cross an active runway clear? Was there a delay in the FO updating the graphical display on the ND? Was that delay important?

- 16 of 19 respondents stated the use of Voice and Data Comm messages to cross an active runway while taxiing was clear.
- 3 of 19 stated they did not like going head down prior to crossing a runway and that the Data Comm message was probably not necessary (however they acknowledged during the verbal debrief session that there was a need to have correct displays that matched Voice instructions, which was the rationale for both Voice and Data Comm messages).
- Almost all crews noted they did not like going head down prior to crossing the active runway (undefined number).

Question 6: How would CDTI (Cockpit Display of Traffic Information) impact your workload, SA, and acceptability of using Data Comm messages in terminal airspace or surface operations?

- 19 of 20 respondents stated the inclusion of CDTI in the cockpit would have a positive impact on their workload, SA, and acceptability of Data Comm in the terminal airspace and surface operations. Of those 19, several also noted that it might cause less head up time, however it would be very useful in low visibility conditions and reducing radio congestion, and in general the benefit would outweigh the potential cost.
- 1 of 20 respondents stated it would slow operations if the information was too cluttered.

Question 7: Was the use of Voice by the controller for critical or time-sensitive information (such as crossing the runway) appropriate and necessary?

- 20 of 20 respondents stated the use of Voice communication for critical or time sensitive information was appropriate and necessary.

Question 8: Were there any challenges with Data Comm unique to your flight duties as the PF or PM?

- 4 of 8 respondents noted that the PM had a significant decrease in head up time and a significant increase in workload due to Data Comm.

- 2 of 8 respondents stated it was difficult for the PF to stay in the information loop while using Data Comm, and that it was important to prioritize messages and tasks.
- 2 of 8 respondents found it difficult to keep the CDU and ND aligned with the most current Data Comm message, and the Data Comm downlink response on Page 2 of the message led to less head up time and more errors in the use of Data Comm.

Question 9: Do you have any other comments? Include any unexpected events, operational issues, and any problems with the simulator that affected your performance.

- 4 of 11 respondents stated they preferred Data Comm, especially when integrated with the MMD and route. Of those four, 1 of them stated Data Comm without the taxi route graphically displayed would be limited to providing a benefit only in situations where language was a barrier.
- 4 of the 11 respondents stated Data Comm messages should not be used when time was critical, for any safety related information, or for crossing or entering a runway.
- 2 of the 11 respondents stated Data Comm would greatly enhance the entire air transportation system, and the sooner it was implemented the better.
- 1 of the 11 respondents stated there needed to be a way to visually determine the most recent clearance, for example using a different font or bold text.

4.6 Verbal debrief comments

Following the written post-experiment questionnaire, a verbal debrief session generally lasting 90 minutes was conducted. Topics included questions about the concept, clarifications of the training program, explanation of the scenarios, a discussion of questionnaire items, and questions from the subject pilots. The content of the responses was recorded, but it was impractical to determine the number of respondents that concurred with a response other than a general description such as 'a few', 'some', 'many', or 'most.'

Given the assumptions of the experiment and what the crews experienced for Data Comm in a Segment 2 (2017-2022) environment, the crews made the following comments:

- The flight crew should be able to respond within two minutes to ATC Data Comm Uplink messages in the Terminal Area. One minute is the absolute minimum time required.
- The use of Data Comm above 18,000 feet was generally considered okay, and by some (but not all) to be somewhat less desirable from 18,000 to 10,000 feet MSL.
- Many of the pilots (but not all) stated between 10,000 feet and the Final Approach Fix all Data Comm messages should be limited to only important messages.
- The vast majority of the pilots said Data Comm, and even Voice, should not be used for communication between FAF and clear of runway (but not all pilots agreed).
- Many pilots did consider it acceptable to send the taxi route as a Data Comm uplink "Taxi" message to aircraft between FAF and clear of the runway if no chime is used.
- Many of the pilots had issues with two messages in different modes to cross active runway (timing, priority, etc.). They agreed that an ATC Voice instruction was essential, but most

did not think it was appropriate to go Head Down to acknowledge the Data Comm message. An option was to send the Data Comm message without a chime.

- Two different categories of Data Comm messages: <u>important</u> and <u>informational</u>. ‘Important’ messages imply a change to the aircraft’s route and require a timely response by the crew (taxi clearance, etc.), and may require the use of an audible chime. ‘Informational’ messages may not meet both criteria (new altimeter setting, “Expected Taxi” clearance, etc.), and would probably not use an audible chime.
- Most crews thought “Expected Taxi” messages were useful.
- Most crews thought “Pushback” and “Start” messages should be combined.
- Some crews recommended that Data Comm “Taxi” message end with “Contact ATC on xxx.xx” since a Voice instruction is required to begin moving the aircraft. This would reduce the possibility of the crew beginning to taxi the aircraft without the Voice instruction.
- Many crews recommended that the ATC Voice instruction to begin taxiing be given by the controller without the need for a Voice request from the flight crew. It did not seem to be necessary for the flight crew to request a taxi clearance via Data Comm, then again via Voice.
- All crews except one stated the downlink message response should be on same page as uplink message to reduce Head Down time and potential for flight crew error or confusion while operating the Data Comm equipment.
- A need was identified for a method to handle outdated messages and displays.
- “Expected Taxi” message should include hold short instructions in the text message and red hold short bars when displayed graphically on the ND.
- One pilot suggested the words “Taxi Route” be used when issuing a taxi route message via Data Comm and “Cleared to taxi” when issuing a Voice instruction. The subtle wording difference may more accurately reflect NextGen Data Comm operations, and help prevent the flight crews from inadvertently beginning to taxi after receiving a Data Comm message.

4.7 Operational errors

Several operational errors by the flight crew were observed, all but one of them occurred during the Trust scenarios described in Section 6. However, none of these errors can be solely attributed to the use of Data Comm in a terminal area. Further research will be needed to clarify the impact of Data Comm use to the frequency and magnitude of operational errors by flight crew.

The operational errors observed during the two Trust off-nominal scenarios are listed below.

- 6 of the 11 crews (55%) failed to correctly identify an incorrect D-TAXI clearance after clearing the runway and taxiing to the ramp during an arrival DataComm/MMD+Route scenario. The final clearance included a taxiway previously identified as closed for debris.
- 7 of the 11 crews (64%) failed to correctly identify that the different runway given in their final D-TAXI clearance during a departure DataComm/MMD scenario was too short for takeoff. The runway had previously been identified as shortened due to construction.

The one operational error not during a Trust scenario occurred while taxiing for departure. The PF exceeded 35 knots and departed Taxiway Bravo while turning onto Taxiway Charlie. This error is most likely attributed to operation of a simulator versus an aircraft, and not use of Data Comm.

5 Synthesis of Results

Members of the FAA and NASA Data Comm Airside team developed the experiment hypotheses and design, and additional FAA requests for data analysis were received after NASA gave approval to proceed for this experiment. Therefore, the data and analysis in this section summarize the experiment results in a way to meet the direct requests of the FAA customer.

5.1 Impact of Communication Modality on Flight Crew in the Terminal Area

The first study (S1) investigated the effect of communications modality while using a paper airport diagram on the acceptability of Data Comm (Section 3.2 and 3.4). Hypothesis 1 (Section 3.1) was:

- Pilot workload and situation awareness will differ significantly between Voice and Data Comm communication mode.

Results and statistical comparisons between the Voice/Paper and DataComm/Paper conditions indicate the following:

- No statistically significant difference of NWS PSD (an indicator of PF physical workload) was observed across the Voice/Paper and DataComm/Paper conditions. (Section 4.2.1)
- Taxi speed, an indicator of PF situation awareness (and therefore related to acceptability), showed a statistically significant yet operationally slight (of the order of 2.0 knots) increase on arrivals, and a statistically significant yet operationally slight (again, of the order of 2.0 knots) decrease on departures in the presence of Data Comm. (Section 4.2.2)
- Statistically significant more head down time for both crew roles existed in all altitude bands, in Data Comm/Paper compared to Voice/Paper. This increase in head down time was not deemed operationally unacceptable by the crews, nor was it reflected in workload or SA preference ratings. (Section 4.3.2)
- There was no statistically significant difference in PF head up time while taxiing when comparing Voice/Paper condition and Data Comm/Paper condition, in either arrival or departure scenarios. The PM did spend statistically significantly less head up time in Data Comm/Paper compared to the Voice/Paper condition. (Section 4.3.3)
- Post-scenario workload and SA ratings remained generally favorable (low or adequate workload, upper third of SA scale) in both Voice and Data Comm modalities. For both PF and PM, both while in flight and in surface operations, the Voice/Paper and the DataComm/MMD conditions appeared associated with lower workload ratings. SA was statistically higher for Voice/Paper than any other condition. (Section 4.4.1 and 4.4.2)
- Statistically significant differences were reported by both PFs and PMs with respect to the introduction of operational risk of using Data Comm in the terminal area; however, the mean rating of all crew members found the risk to be operationally acceptable. (Section 4.4.3)
- Post-experiment workload comparison and SA comparison preference ratings improved in the presence of Data Comm. This is opposite of the post-scenario results. Analysis of results based on scenario run order show improved ratings with increased exposure to the operation. Other possibilities for the difference include “experimenter’s bias” (where experiment subjects tend to rate new technology higher to validate the researcher’s work) or the subjects believe there is potential for the technology and rate it higher during post-experiment questionnaires. (Section

4.5.1 and 4.5.2)

- Post-experiment questionnaire results indicate acceptance of Data Comm in the terminal area; however, Voice should be used for time-critical or safety-related communication. (Section 4.5.3 and 4.6)

In summary, pilot workload and SA did differ significantly between Voice and Data Comm communication modes. Workload and SA improved in the presence of Data Comm in post-experiment questionnaire ratings, and was slightly reduced in post-scenario questionnaire ratings.

5.2 Impact of Display Methodology on Flight Crew in the Terminal Area

The second study (S2) investigated the effect of display methodology while using data communications on the acceptability of Data Comm (Section 3.2 and 3.4). Hypothesis 2 (Section 3.1) was:

  - Pilot workload and situation awareness will differ significantly between display modes when using Data Comm.

Results and statistical comparisons between the DataComm/Paper, DataComm/MMD, and DataComm/MMD+Route conditions indicate the following:

- No statistically significant difference existed in mean response times to Data Comm messages by display methodology. (Section 4.1.1)
- No effect on NWS PSD (an indicator of PF physical workload) was observed across experimental conditions on arrivals, but there was a significant increase in NWS PSD in departures with respect to display methodology. NWS PSD increased going from paper to MMD, and from MMD to loadable routes. (Section 4.2.1)
- Taxi speed showed a statistically significant (of the order of 4.0 knots) increase during arrival scenarios, between the DataComm/MMD to DataComm/MMD+Route condition. There were no statistically significant differences during departure scenarios, regardless of display methodology. (Section 4.2.2)
- In general, there was no statistically significant difference for either PF or PM head up time across the three display conditions. The one exception was both PF and PM had statistically significant less head up time in the Data Comm/Paper condition compared to the other two display conditions. (Section 4.3.1)
- More head down time, in both crew roles, existed in the low (5K-7K ft) altitude band in the presence of Data Comm, proceeding from paper, to MMD, and MMD+Route display methodology. This increase in head down time was not deemed unacceptable by the crews, nor was it reflected in workload or SA preference ratings. (Section 4.3.2)
- Post-scenario workload ratings by PFs and PMs remained favorable (75% of responses scored "3" or less) in all Data Comm scenarios, regardless of display methodology. PF workload was statistically higher than PM workload during Data Comm (except for surface operations when in Data Comm/MMD+Route condition), though still in the adequate region. (Section 4.4.1)
- Post-scenario ratings by the PFs scored the flight operation workload significantly different among the display conditions (worst to best of DataComm/Paper, DataComm/MMD, DataComm/MMD+Route). The PMs did not rate inflight operations significantly different. Both PF and PM rated surface taxi operations significantly different among the display conditions (PF

worst to best of DataComm/Paper, DataComm/MMD, DataComm/MMD+Route, and PM of DataComm/Paper, DataComm/MMD+Route, and DataComm/MMD). (Section 4.4.1, Table 46, Table 47)

- Post-scenario SA ratings were statistically higher for Voice/Paper than any Data Comm condition. (Section 4.4.2)
- Post-scenario SA ratings remained favorable (upper third of SART scale) in all Data Comm scenarios, regardless of display methodology. Display condition did not have a statistically significant impact on SA ratings of either the PF or PM. (Section 4.4.2)
- Post-experiment workload comparison and SA comparison preference ratings, for both airborne and surface operations, improved when the MMD was available, and again, when implementing loadable routes on the MMD. (Section 4.4.4 and 4.4.5)

In summary, pilot workload and SA differed significantly by display methodology when using Data Comm. Display methodology did not have a statistically significant impact on SA ratings for either the PF or PM.

5.3 Acceptability of Data Comm Use to Flight Crew in the Terminal Area

This section collates analyses that addresses whether the flight crew found the use of Data Comm in a busy terminal area to be acceptable. This was defined in Hypothesis 3 as:

- Pilots will rate the Data Comm used within this experiment as operationally acceptable.

Results and statistical comparisons indicate the following:

- Mean response time to Data Comm messages was 20.7 seconds, with over 95% of the responses occurring under one minute and 97% occurring under two minutes. A statistical difference of approximately six seconds was found between the two lowest Conditions (Arrival/MMD and Arrival/MMD+Route) and the highest condition (Departure/MMD+Route); however, the difference in response times is not considered operationally significant. (Section 4.1.1, 4.1.2)
- Approximately 3% of the Data Comm messages were not responded to within two minutes. Researcher observation and flight crew comments during the post-experiment debrief session indicated these late responses were due to the crew believing they had responded using Page 2 of the Data Comm message, or forgetting to acknowledge. In all cases, the message was read and briefed to the other crew member, and the crew had time available to respond. (Section 4.1.2)
- A statistically significant difference of the mean message response time of approximately four seconds was found between Data Comm arrival and departure scenarios, however, this is not considered operationally significant. (Section 4.1.1)
- A statistically significant difference between mean response time to a frequency change message compared to an Expected Taxi message of ten seconds was found, and this could be considered operationally significant. (Section 4.1.1 and 4.1.2)
- Post-scenario acceptability ratings remained high for all Data Comm scenarios. On a scale of 1 (completely acceptable) to 7 (completely unacceptable), the mean rating for all Data Comm conditions by the PF was 2.7, and by the PM was 1.9. (Section 4.4.3, Table 79)
- During post-scenario questionnaires, crews indicated that Data Comm during approaches above 10,000 feet MSL would be acceptable. 82% of the crews reported that Data Comm messages

from 10,000 feet to the Final Approach Fix could be sent by controllers; however only 60% felt the crews would always be able to respond within two minutes. Post-experiment questionnaire responses indicated 82% of the crews felt that the use of Data Comm as the communication modality was acceptable as experienced in this high traffic density and high workload terminal area environment. (Section 4.4.6 and 4.4.8)

- Post-experiment workload comparison (Section 4.4.4) and SA comparison (Section 4.4.5) preference ratings were generally high, and improved in the presence of Data Comm.
- All crews indicated that Data Comm should not be used between the FAF and 80 knots during landing roll-out. However, many crews also stated Data Comm messages during that time would be acceptable if they were not accompanied by a chime and the flight crew was not expected to immediately respond to the message. (Section 4.4.6)
- Crews indicated the use of Voice communication to cross an active runway while taxiing was necessary and appropriate. It was also stated the simultaneous use of a Data Comm message was not appropriate since it caused crew members to go head down at a critical time. Use of a Data Comm message without a chime was considered an acceptable alternative. (Section 4.4.8 and 4.4.9)

In summary, pilots rated Data Comm (as implemented within this experiment) as operationally acceptable in a complex and busy terminal area environment.

6 Exploratory Study: Rare Event Scenario and Trust Assessment

The purpose of the rare event scenarios was to test the impact of incorrect Data Comm messages on the flight crew's trust in the accuracy of the information. Errors in data transmission can undermine a crew's confidence in automation, as well as their faith in the integrity of the information. This section discusses the two Data Comm scenarios that captured the pilot's perceptions of trust (these two runs and the data collected are not part of the text and conclusions in the remainder of this text). The summary of data collected and analyzed during these two runs is presented here, with complete data in Appendix P.

6.1 Rare Event Scenarios

Research on trust in automation has typically been tailored to an experiment in which there is a contrived failure within a system which must be detected, diagnosed and resolved, either through the aid of automation or through human intervention. After the scenarios, subjects are queried on their faith in the system and whether or not they perceived that faith to present an operational risk. Additionally, subjects were asked questions pertaining to their perception of the reliability and dependability of the automation, personal attachment to the automation, and their confidence in the automation to perform routine tasks typically performed by the human operator(s). [37][38][39]

For this experiment, two scenarios were created with events that, in the course of flight operations, might cause pilots to lose confidence in the electronic delivery of a taxi instruction. Subjects were advised prior to the simulator portion of training, that during the course of the experiment, there would be a potential for human error, with respect to clearances provided (just as in real-world scenarios).

The first rare event occurred in the final (fourth) training scenario, and was a Norwich Three arrival operation with Data Comm and MMD+Route display. The ATIS noted that taxiway Alpha-1 (A1) was closed due to debris. Upon landing, the flight crew received a D-TAXI message to turn off the active runway and taxi to the terminal via N-B-L-A, a feasible taxi route. This clearance was amended to taxi via B-A1-A, an infeasible taxi route since A1 was closed for debris. As soon as the crews recognized the inappropriate clearance, the scenario was ended. If they proceeded despite the inappropriate clearance, they would be able to see that there was a baggage cart placed near the center of the taxiway, and the scenario was ended when they stopped the aircraft and queried ATC. Had the crew accepted the clearance and not seen the cart, a ground collision would have occurred between the aircraft and baggage cart. Of the eleven crews, six (55%) failed to process the inappropriate clearance (but stopped upon noticing the baggage cart). Of those six crews, one taxied past the cleared taxiway (primarily due to a delay in responding to the Data Comm amended taxi clearance message).

The second scenario occurred after the sixteen data collection runs for each crew, and was a departure scenario with Data Comm and MMD display. This scenario was a departure scenario, initially to Runway 15R at KBOS, then changing to Runway 27. ATIS messages delivered before and after the runway change indicated that the first 2,000 ft. of Runway 9 were closed due to maintenance (equivalent to the last 2,000 ft. of Runway 27). Two feasible Expected Taxi clearances were sent to the flight crew to taxi to Runway 15R, an appropriate runway for takeoff. The final D-TAXI clearance was provided to Runway 27, an inappropriate runway for takeoff due to insufficient length for the aircraft weight. The scenario was ended either when crew narrative comments indicated they recognized that the scenario presented a potentially unsafe takeoff situation, or when they taxied on to the runway for takeoff not having processed the potentially unsafe situation of a shortened runway. Had the crew accepted the takeoff clearance for the shortened runway at that aircraft weight, a serious mishap would most likely have occurred since the takeoff distance required exceeded the 5000 feet available on Runway 27. Seven of the crews (64%)

accepted the unsafe clearance on to the runway for takeoff. The remaining four crews correctly assessed this as a potentially unsafe situation and ended the scenario.

In all cases, post-experiment recorded comments indicated that the rare event scenarios were considered possible, and at least somewhat realistic. One crew member indicated he had been a member of a flight crew during a real world operation of essentially the departure scenario rare event.

6.2 Trust Questions and Results

Trust questions were incorporated into both the post-scenario and the post-experiment questionnaires. The post-scenario questions focused on accuracy of the loading of the route onto the moving map display, time constraints for responding to the taxi instructions regardless of the modality (Voice versus Data Comm), and whether or not the implementation of Data Comm posed an operational or safety risk. The post-experiment questionnaire targeted other constructs of confidence, verification, detection, integrity, reliability, and elements of uncertainty – ambiguity and completeness.

The subject pilots were asked to compare their perceived Trust among the four conditions (Appendix P.4), and a summary of the results are shown in Figure 34. In this comparison, both the PF and PM preferred the Data Comm / MMD+Route condition.

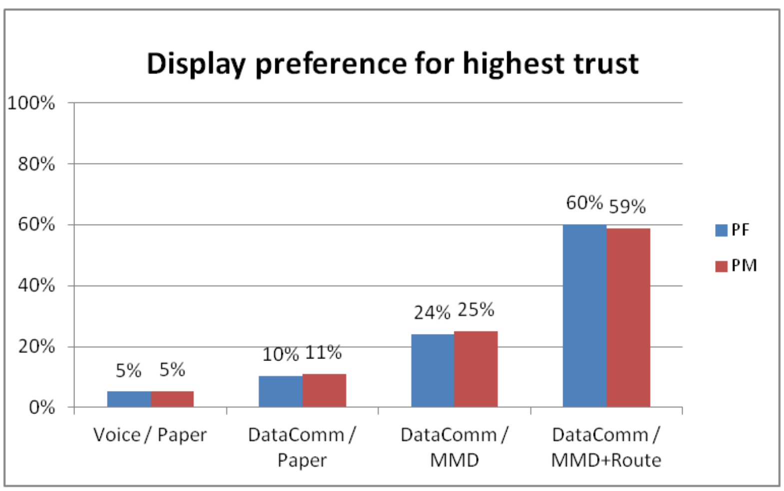


Figure 34. Display preference for highest trust by condition

Trust Question 1: Overall, how confident were you that the data linked message was properly loaded into the FMS and then graphically displayed on the ND? (1 – Complete Confidence; 7 – No Confidence)

- Summary of results from Appendix P.4, question #1, is shown in Table 33.
- Subject pilots generally had a high level of confidence in the loading of the Data Comm message so that it would create a graphic of either the ownship on the airport or the combination of the ownship and a route map. Median scores for all crews was 2 (N=22, SD=0.99).

Table 33. Confidence Data Comm message displayed properly on ND

	N	Minimum	Maximum	Median	Standard Deviation
Trust 1	22	1	4	2	0.99

<u>Trust Question 2</u>: How often did you verify the accuracy of the data link taxi instructions? (1 – All The Time; 7 – None Of The Time)

- Summary of results from Appendix P.4, question #2, is shown in Table 34.
- The median rating for verifying the accuracy of Data Comm instructions among subjects was 1 (N=22, SD=1.35). This suggests that pilots verified the Data Comm message content by analyzing the airport diagram or the map. It was not clear whether or not this was due to mistrust of the information, creation of a mental map, or due to company policy. Verification could be linked to lack of trust, but it could also be a policy of the flight crew and/or organization to confirm information.
- Comment: Some pilots indicated that they didn't verify the instructions because they presumed it was accurate or the other crew member had compared the instruction with the moving map.

Table 34. Verification of D-TAXI instruction feasibility

	N	Minimum	Maximum	Median	Standard Deviation
Trust 2	22	1	6	1	1.35

<u>Trust Question 3</u>: How often did you verify the taxi route displayed on the Navigation Display with the Data Comm message on the CDU? (1 – All The Time; 7 – None Of The Time)

- Summary of results from Appendix P.4, question #3, is shown in Table 35.
- The median score among subjects for verification was 1 (N=22, SD=0.95). This indicates that most of the time pilots verified the taxi route on the ND with the Data Comm message on the CDU.
- Comments: The question may not have captured the intended purpose of this inquiry to determine if pilots trusted the automation. Research suggests that verification indicates a lack of trust. However, when asked, two of the pilots stated it was company policy to always verify information. Other pilots indicated that they didn't verify the instructions against the moving map because they presumed it was accurate or they believed that the other crew member had compared the instruction with the moving map.

Table 35. How often was D-TAXI instruction verified for correct display on MMD?

	N	Minimum	Maximum	Median	Standard Deviation
Trust 3	22	1	5	1	0.95

<u>Trust Question 4</u>: How long did it take you to notice the data link message was incorrect? (1 – Did Not Notice It Was Incorrect; 7 – Noticed Immediately)

- Summary of results from Appendix P.4, question #4, is shown in Table 36.
- The median score was 5 (N=19,SD=2.07). This indicated that most pilots felt they correctly noticed when the Data Comm message was incorrect (either the closed taxiway, or construction on

a runway that made it too short for takeoff). This is inconsistent with their performance; given that most crews did not detect the inappropriate clearances (the reason for this discrepancy is not known). Three subjects did not respond to the question, with two indicating it was not applicable to any of the scenarios they experienced. Observations of flight crews demonstrated a range of behaviors and attention towards information provided. Two first officers turned the ATIS off after getting specific information about the wind, temperature, dew point, altimeter and active runway. These crews missed the rare event information that would affect their taxi route or takeoff.

Table 36. How long did it take to notice data link message was incorrect?

	N	Minimum	Maximum	Median	Standard Deviation
Trust 4	19	1	7	5	2.07

<u>Trust Question 5</u>: The method for receiving, uploading, and carrying out air traffic taxi instructions via Data Comm has integrity, is reliable, is incomplete, and is ambiguous. (1 "No" to 7 "Yes").

- Summary of results from Appendix P.4, question #5, is shown in Table 37.
- During analysis, the scores were analyzed on a seven point scale to capture moderate perceptions. In addition, ratings for incompleteness and ambiguity were reverse coded to normalize values for data analysis. The median score for Integrity was 6 (N=22, SD=0.90) indicating a high sense of integrity for Data Comm in general, and pilots felt the system was generally reliable with a median score of 6 (N=22, SD=0.79). For incompleteness, pilots felt the system provided nearly complete messaging with a median score of 2 (N=22, SD=1.67). Pilots also felt that the system was not ambiguous, with a median score of 1.5 (N=22, SD=1.19).
- Summarizing the results for Trust Question 5, the subject pilots' attitude toward trusting the Data Comm system was high considering the constructs of confidence, accuracy, risk, integrity, and reliability. Even when anomalies occurred, pilots indicated they would contact ATC for clarification. Incorrect information sent via Data Comm did not appear to impact the subjects' trust in the system.

Table 37. Integrity, reliability, incompleteness, and ambiguity of Data Comm

Trust 5	N	Minimum	Maximum	Median	Mean	Standard Deviation
Integrity	22	4	7	6	6.05	0.90
Reliability	22	5	7	6	6.05	0.79
Incomplete	22	1	7	2	2.27	1.67
Ambiguity	22	1	5	1.5	1.91	1.19

Overall, this study indicated that Trust was not impacted by errors in the Data Comm message itself. Constructs of integrity, confidence, and reliability did not appear to be affected when pilots encountered contradictions in instructions caused by incompleteness or accuracy. However, pilots did not feel the need to verify the message, indicating a level of complacency with not only the automation but the reliance of one pilot on the other for processing information.

7 Conclusion

The FAA worked with NASA Langley Research Center to study the impact caused by the use of Data Comm on flight crew during terminal area operations. Crews' qualitative comments indicated in general an acceptance of Data Comm use in the terminal area as experienced within this experiment, and favorable ratings of workload and SA. Qualitative data showed that crews found the decrease in head up time associated with Data Comm use to be acceptable. There was also consensus in acceptability and desirability of employment of a Moving Map Display, particularly in conjunction with loadable routes, in the presence of Data Comm.

In general, there was a desire to limit Data Comm during certain critical phases when it was important for the crew to be head up. However, the crews also stated that even in these phases, Data Comm could potentially be acceptable if there was an improvement to the ease of responding and a reduction in the intrusiveness of chimes and alerts. The two identifiable segments where the majority of crews found the use of Data Comm unacceptable were:

1) From the Final Approach Fix to approximately 80 knots during landing rollout
2) While crossing an active runway during taxi operations

Quantitative results showed that within the scope of this experiment, the use of Data Comm in the terminal area was acceptable in terms of perceived workload, SA, and flight technical performance. Though statistical differences were identified that favor PF workload in Voice modality and SA in the Voice/Paper condition, all PF and PM workload and SA ratings using Data Comm remained acceptable.

Within the scope of this experiment, the use of two minutes as the expected time for Data Comm message downlink responses is consistent with the quantitative and qualitative data observed. The observed mean response time was 20 seconds, with over 95% of all messages responded to in less than one minute. However, debrief comments from all the crews indicated they felt one minute was not quite sufficient and two minutes would be significantly better.

The crews rated the Expected Taxi message as useful in both arrival and departure scenarios. Most crews also commented that the text instruction should include hold short instructions, and graphical displays should include red hold short bars.

Effects of Data Comm during arrival scenarios in the presence of paper airport diagram utilization included a no effect on NWS activity and statistically significant, but perhaps not operationally significant decreases in head up time for the PMs (only), and minor increases in taxi speed. Effects of Data Comm employment during departure scenarios in the presence of paper airport diagram utilization included a statistically significant, but perhaps not operationally significant decreases in head up time for both crew, and decreases in taxi speed.

The introduction of route symbology on the MMD while using Data Comm produced a minor increase in NWS Rate activity in departures only, and a minor decrease in head up time in the case of the PM for arrivals only. Crew preference for MMD employment during both arrivals and departures, particularly with loadable routes, in terms of workload and SA, was strong.

Crew head up scan time while inflight was approximately 10%, and during surface operations approximately 60% for the PF and 35% for the PM. Head up scan time was impacted by display condition.

8 Recommendations and Future Research

The following three sections are prioritized lists of recommendations from researcher observations and flight crews comments about procedures, avionics, and future research. This Section was created in response to discussions with the FAA Data Comm Program representatives to document information that was not directly derived from the experiment hypotheses and data collection, and to propose topics for future research of flight crew use of Data Comm in a terminal area environment.

8.1 Controller-Pilot Operational Procedure Recommendations

1. Either "Start" or "Pushback" Downlink request should be sent, but not both.

2. The "Taxi" uplink clearance should be sent automatically at some set time after the "Pushback" uplink was sent, it should not be required to have the flight crew send a separate downlink request.

3. The "Taxi" uplink clearance message should end with text that states: "Contact GRND on xxx.xx" if Voice communication from ATC is required to begin moving the aircraft. This applies when taxiing from the terminal to the runway and taxiing from the runway to the terminal.

4. Two minutes should be allotted for the flight crew to read, brief, and respond to Data Comm messages or take action related to that message when in the terminal area. One minute is the absolute minimum.

5. Data Comm implementation strategies that require the crew to look down at a CDU to respond to a message when cleared to cross an active runway should be avoided.

6. Implementation for communicating significant airport surface information to flight crews should be structured so that the rare events are not likely to occur (such as this experiment's rare event scenario that closed taxiways and shortened runways). Examples of methodology to support this requirement would be linking D-ATIS content to MMD display graphics and requiring runway remaining markers to be covered or altered when they are inaccurate for existing conditions.

8.2 Aircraft Avionics Implementation Recommendations

1. Crew should have the ability to respond to a Data Comm message on the same page as the message itself. That would reduce workload and the probability of the crew thinking they had acknowledged the Data Comm message but had not (this was the root cause for a significant portion of the delayed crew responses). On the other hand, one pilot recommended retaining a two page set-up to prevent accidental responses, which he thinks are likely especially when the crew is busy and trying to move quickly. However, that error never occurred, while almost every crew at least once thought they had responded to the Data Comm message and were executing it, yet had not acknowledged it.

2. If one crewmember selects a new Data Comm message of the same type as the other crew member currently has displayed on their CDU, the other crew member's CDU should automatically display the new message as well. This was felt to be important by many subject pilots to reduce the possibility of one crew member reviewing and acting on an outdated Data Comm message. This is particularly important for Taxi messages, and several times during the experiment the FO

acknowledged an AMENDED TAXI clearance while the Captain still had the original TAXI clearance displayed on his CDU. NOTE: Other options include erasing the old message, or including text in the page displaying the message saying OUTDATED.

3. The Moving Map Display (MMD) should automatically load the graphical representation of the route sent by Data Comm. This would reduce workload and the number of times the crew forgets it is available. This option may require the option to erase the route.

4. The WILCO/ROGER letters should be removed from the acknowledgement page once the message has been acknowledged to make it clear the crew has already responded.

5. The Data Comm interface device would be separate from the interface device for the FMS since the CDU is needed for critical navigation tasks.

6. The Start/Pushback/Taxi downlink requests should each take only one button push on one page.

7. "Expected Taxi" message should include hold short instructions, and the display should include hold short bars.

8. The word DISPLAY should be used instead of LOAD to display the route on the ND. This will assist in differentiating from current Data Comm route clearances that are LOADED into the FMS, which changes the aircraft's flight path (D-TAXI does not).

9. The flight crew would benefit from the ability to delete or archive specific types of messages (ATIS, altimeter, "Expected Taxi") while retaining others.

8.3 Future Research Issues

1. How can the flight crews' degradation of SA due to loss of information from "party-line" Voice communication be offset by incorporating the use of CDTI (TCAS and ADS-B "In")?

2. What is the acceptability and impact of conducting more complex NextGen type flight operations that require other CPDLC messages, such as trajectory reroutes and speed change messages?

3. What is the impact of allowing flight crews to use the auto-pilot for NextGen procedures?

4. What are other options to crossing an active runway than those explored in this experiment (simultaneous Voice and Data Comm messages from ATC)?

5. What procedures and mitigation strategies should exist when the flight crew receives, understands, and is executing Data Comm message, but forgets to respond to ATC about the message?

6. How can Data Comm be functionally integrated with D-ATIS to graphically display closed taxiways, construction areas, changes to runway length, etc.?

7. How can Data Comm be functionally integrated with other runway incursion prevention devices, such as red hold short bars that are controlled by ATC?

8. Are there operational issues that would be discovered by utilizing subject controllers and subject pilots in the same scenario?

9. When does the flight crew need to uplink both a “Start” and a “Taxi” Data Comm request? Are there options to have the second message occur automatically after a pre-determined time interval?

10. Would the use of “Route” be more distinct and accurate than “Clearance”? (Example: the Data Comm downlink message from ATC would be “Expected Taxi Route”, “Taxi Route”, or “Amended Taxi Route”. This differentiates it from today’s “Clearance” which gives the crew authority to begin moving the aircraft, whereas a Data Comm instruction does not.)

11. How important is it that the “Expected Taxi” route be close to the actual “Taxi” route?

12. What happens if a crew does not respond to an “Amended Taxi” clearance while taxiing, or responds after they have passed the new route?

13. Is a Voice call to Ground necessary after the crew acknowledged the Data Comm “Taxi” clearance? For example, after an aircraft lands and has acknowledged a Data Comm “Taxi” clearance, does the flight crew also need to acknowledge the taxi clearance via voice communication?

14. If the Data Comm message is erased or archived, would/should that erase any taxi routing displayed on the ND?

15. Should specific chime sounds (including no sound) be used to indicate the priority or urgency of the message?

References

[1] *Data Communications National Airspace System Human-in-the-Loop Simulation, Airside Research Request*, FAA ATO Ops Planning, Air Traffic Systems Concept Development and Validation Group, Final Draft Version 1.4, 30 Dec 2008

[2] *Reimbursable Interagency Agreement IA1-973 Between FAA and NASA Langley Research Center for Enhancement of Aeronautical Research and Technology Development*, 10 June 2009

[3] *Concept Of Operations for the Next Generation Air Transportation System*, Version 3.0, Joint Planning and Development Office (JPDO), Washington DC, 1 October 2009

[4] *Interoperability Requirements Standard for Aeronautical Telecommunications Network Baseline 1*, RTCA DO-280B, Vol 1 of 2, June 26, 2007

[5] *Interoperability Requirements Standard for Aeronautical Telecommunications Network Baseline 1*, RTCA DO-280B, Vol 2 of 2, June 26, 2007

[6] *Data Communications Human Factors Discussion paper, Segment One, Aircraft/Flight Crew HF Challenges*, FAA ATO Data Comm HFWG-08, March 28, 2008

[7] Herschler, D., *NextGen Human Factors in Data Communications*, FAA Human Factors Research and Engineering Group (AJP-61), June 1, 2009, Version 6.0

[8] *LINK 2000+, Flight Crew Datalink Operational Guidance for LINK2000+*, Ver 4.0, 30 Jun 09

[9] Pinska, E., Whiteley, M., *LINK 2000+, France Real-Time Simulation Project*, Eurocontrol Experimental Center, EEC Report No. 395, Sept 2004

[10] *D-TAXI Trial Final Report*, Version 2.0, EUROCONTROL CASCADE Programme, April 2007

[11] Roeder, M., *EMMA Publishable Final Activity Report*, Deutsches Zentrum fur Luft und Raumfahrt (DLR), D013, 17 Sept 2007

[12] Jakobi, J., *EMMA Recommendations Report*, Deutsches Zentrum fur Luft und Raumfahrt (DLR), Document D6.8.1, 2007

[13] Teutsch, J., *EMMA2 Validation Comparative Analysis Report* (European Airport Movement Management by A-SMGS, Part 2), National Aerospace Laboratory of the Netherlands (NLR), Document No. 2-D6.7.1, Version 1.0, 2009

[14] Jakobi, J., *EMMA2 Recommendations Report* (European Airport Movement Management by A-SMGS, Part 2), DLR, Document No. 2-D6.7.2, Version 1.0, 2009

[15] Jakobi, J., Teotino, D., Montebello, P., *Higher-Level Services of an Advanced Surface Movement Guidance and Control System (A-SMGCS)*, ATC Quarterly, in press

[16] Volker, Stuhlsatz, *Air/Ground Data Link Procedures For Flights Within The Area of Responsibility of Maastricht-UAC*, Eurocontrol, Edition 2.5, 31 July 2008

[17] Waller, M., Lohr, G., *A Piloted Simulation Study of Data Link ATC Message Exchange*, NASA TP-2859, Feb 1989

[18] Harvey, C., Reynolds, M., Pacley, A., Koubek, R., Rehmann, A., *Effects of the Controller-To-Pilot Data Link on Crew Communication*, Wright State University, FAA WJHTC, 46th Human Factors and Ergonomics Society Annual Meeting, pages 61 – 65, 2002

[19] Scanlon, C., Know, C., *Flight Test Show Potential Benefits of Datalink as Primary Communication Medium*, SAE Aerospace and Technology Conference, 1990

[20] Knox, C., Scanlon, C., *Flight Tests With a Data Link Used for Air Traffic Control Information Exchange*, NASA TP-3135, Sept 1991

[21] van Gent, R., *Human Factors Issues with Airborne Data Link*, National Aerospace Laboratory of the Netherlands (NLR), AIAA Guidance, Navigation, and Control Conference, San Diego, AIAA-1996-3855

[22] Rehmann, A., *HF Recommendations for Airborne CPDLC Systems: A Synthesis of Research Results and Literature*, ACT-350, DOT/FAA/CT-TN97/6, June 1997

[23] Lee, K., Sanford, B., Slatterly, R., *The Human Factors of FMS Usage in The Terminal Area*, NASA Ames, AIAA Modeling and Simulation Technologies Conference, New Orleans, AIAA-1997-3804

[24] Prinzo, O., *United States Airline Transport Pilot International Flight Language Experiences Report 2: Word Meaning and Pronunciation*, DOT/FAA/AM-10/7, April 2010

[25] Hooey, B., Foyle, D., Andre, A., Parke, B., *Integrating Datalink and Cockpit Display Technologies into Current and Future Taxi Operations*, Proceedings of the AIAA/IEEE 19th Digital Avionics System Conference, Philadelphia, PA, Oct 2000

[26] Hellenberg, J., Wickens, C., *Pilot Expectancy and Attentional Effects for Hazard Awareness: Effects of Data Link Modality on Pilot Attention and Communication Effectiveness*, University of Illinois, Tech Report ARL-00-7/FAA-00-4, Aug 2000

[27] Mueller, E., Lozito, S., *Flight Deck Procedural Guidelines for Datalink Trajectory Negotiation*, NASA, AIAA ATIO Conference, AIAA 2008-8901, Sept 2008

[28] Rehmann, A., *Flight Simulator Evaluation of Baseline Crew Performance with Three Data Link Interfaces*, FAA Technical Center, DOT/FAA/CT-TN95/19, Sept 1995

[29] Parke, B., Renfroe, D., Kanki, B., Hooey, B., Munro, P., Patankar, K., Foyle, D., *The Effects of Advanced Navigation Aids and Different ATC Environments on Task-Management and Communication in Low Visibility Landing and Taxi*, 11th International Symposium on Aviation Psychology, Ohio State University, March 2001

[30] Navarro, C., Sikorski, S., *Datalink Communication in Flight Deck Operations: A Synthesis of Recent Studies*, University of Toulouse, The International Journal of Aviation Psychology, pg 361-376, 1999

[31] Lozito, S., Verma, S., Martin, L., Dunbar, M., McGann, A., *The Impact of Voice, Data Link, and Mixed Air Traffic Control Environments on Flight Deck Procedures*, FAA/Eurocontrol ATM Conference, 2003

[32] Prinzel, L., Shelton, K., Jones, D., Allamandola, A., Arthur III, J., Bailey, R., *Evaluation of Mixed-Mode Data-Link Communications for NextGen 4DT and Equivalent Visual Surface operations*, Air Traffic Control Quarterly, Vol 18, Issue 2, 2010

[33] *Data Communications Safety and Performance Requirements*, RTCA SC-214/EUROCAE WG-78, Draft E, 30 April 2009 [Note: this version of the SPR document complies with guidance in RTCA DO-264/EUROCAE ED-78A, and used to provide input to RTCA DO-305A published in 2012.]

[34] Roscoe, A. H., Ellis, G. A., *A Subjective Rating Scale For Assessing Pilot Workload In Flight: A Decade Of Practical Use*, Royal Aerospace Establishment, Bedford, UK, 1990

[35] Taylor, R. M., *Situational Awareness Rating Technique (SART): The development of a tool for aircrew systems design.* Proceedings of the AGARD AMP Symposium on Situational Awareness in Aerospace Operations. Seuilly-sur Seine:: CP478. NATO AGARD, 1989

[36] FAR|AIM 2010, *Federal Aviation Regulations and Aeronautical Information Manual*, ASA Inc., Newcastle, WA, 2010

[37] Lewandowski, S., Mundy, M., Tan, G.P.A., *The Dynamics of Trust: Comparing Humans to Automation*, Journal of Experimental Psychology: Applied, Vol 6(2), June 2000, pg 104-123

[38] Lee, J., Moray, N., *Trust, Control Strategies and Allocation of Function in Human-Machine Systems*, Vol 35 (10), Ergonomics, Oct 1992, pg 1243-1270

[39] Madhavan, P, Wiegmann, D.A. & Lacson, F.C., *Occasional Automation Failures on Easy Tasks Undermines Trust in Automation*, Human Factors: The Journal of the Human Factors and Ergonomics Society, 2006

[40] MINITAB Inc., (2005), MINITAB Help v 14.20. Hampton, VA.

Appendix A: FAA/NASA Interagency Agreement

A.1 FAA/NASA Interagency Agreement

Once the FAA and NASA leadership agreed in principal to the collaboration, the agreement was codified in an Interagency Agreement. The following paragraphs of this section are excerpts from FAA/NASA Reimbursable Interagency Agreement IA1-973 [1] and the Airside Research Request [2].

> NASA Langley Research Center (NASA LaRC) and the Department of Transportation/Federal Aviation Administration (DOT/FAA) enter into this Technical Direction for the purpose of collaborative research activities to ensure effective development and implementation of data communications in the future Air Traffic Management environment. The focus of this agreement is on (1) the development of a Test Plan for the conduct of a Human-in-the-Loop Simulation designed to address specific key issues in the successful development and implementation of data linked communications, (2) the implementation of the Test Plan to conduct a Human-in-the-Loop Simulation at the NASA Langley Research Center, and (3) the analysis and reporting of results obtained from the simulation testing. [1]
>
> High-level guidance comes from the FAA Data Communications National Airspace System Human-in-the-Loop Simulation, Airside Research Request, December 30, 2008, Version 1.4, and any subsequent updates or revisions as mutually agreed to during the execution of this Agreement by the FAA and NASA. [2]

When using Data Comm, taxi instructions are delivered through the data link system to the airplane's cockpit systems/avionics and then displayed as text to the pilot, rather than delivering them through the radio. Key research issues used as dependent variables include pilot performance, pilot errors, head-down time, workload, and message dialog and reply times.

A.2 Assumptions Contained in Interagency Agreement and Addendum

The following assumptions are specified in the 30 July 2009 Addendum to the Agreement, and subsequently expanded upon in the final FAA/NASA Data Comm Test Plan: [1] [2]

- NASA and FAA shall make an effort to incorporate scenarios that maximize similarities between the GENERA airport diagram (used FAA Technical Center's Research Development and Human Factors Laboratory, or RDHFL), and the airport selected for this study.
- Consistent with the expected capabilities and functions in Segment 2 (2017-2022), the test plan will focus on the terminal domain and shall use realistic traffic levels.
- The study shall be conducted using instrument flight rules in day visual meteorological conditions.
- Real-world arrival and taxi routes, procedures, and operations will be simulated to the maximum extent practicable.
- Checklists and performance data will be provided to the crews. Communications and navigational facilities and procedures will be simulated to the maximum fidelity feasible.
- The departure phase of operations shall consist of taxiing from the gate onto position-and-hold of the departure runway. Two "Expected Taxi" messages will be given while the aircraft is at the

gate and prior to push back, one “Taxi” message will be given after pushback and with the engines running, one “Amended Taxi” message will be given to change the taxi route prior to reaching the intersection of an active runway, and an “Amended Taxi” message will be given to cross the active runway.

- The arrival phase of operations shall consist of flight from 18,000 feet MSL and terminate at the gate. Two “Expected Taxi” messages will be given while airborne, one Taxi message will be given during landing roll-out, and one “Amended Taxi” to change the taxi route will be given after clear of the runway.
- Ten 2-pilot crews shall be utilized, each for one full test day. NASA will recruit Airline Transport Pilots with Boeing 757 or 767 type-rating with current or recent flight experience.
- Datalink and Voice communications shall be utilized.
- Voice synthesis (real-time text to speech generation) shall not be used.
- Pre-recorded air traffic control communications (both directive and party-line) shall be used with researcher intervention when necessary.
- The Class D-level Integration Flight Deck (IFD) simulator in a fixed-base platform configuration will be used.
- The content, size, and location of the ND shall not constitute a Data Comm-research question but may be used to display graphical data link taxi (D-TAXI) clearances (graphical displays shall include a moving map, with own ship, and taxi route). [Amplifying comment: ND location will not be varied, displayed route size and color will not be varied.]
- The location of the Data Comm display will be kept constant.
- The control display unit (CDU) will be the main display to emulate Data Comm messages.
- NASA will emulate a Future Air Navigation System-1/A (FANS-1/A) capable flight management system (FMS) CDU, and subsets of the FANS-1/A message sets.
- The following documents are references for Data Communications messages and FANS-1/A: DO-219, -256, -269, -287, -305 and -306, as well as current SC 214 documents (Safety and Performance Requirements).
- D-TAXI clearances shall be delivered via controller-pilot data link communications (CPDLC), other clearances and communications shall be delivered via Voice.
- Free text capability will not be available (need for specific free text scenarios may be assessed in post-experiment questionnaire).
- The time it takes a Data Comm message to travel from ATC to the CDU will be held constant.
- Rare event trials shall be part of the experiment and may include (a) non-D-TAXI tactical CPDLC clearances, (b) obstacles, and/or (c) errors.
- An audible chime shall be incorporated to indicate the reception of CPDLC messages. The same chime shall be used for all CPDLC messages .
- Each crew shall experience D-TAXI out, D-TAXI Expected, and D-TAXI-in, as well as one rare event.
- No Data Comm errors will be modeled. If resources permit, NASA will use procedural errors.

- NASA will emulate ATC instructions. Clearances and background chatter will be pre-recorded.
- NASA will emulate full D-TAXI air traffic control capabilities.
- NASA will emulate realistic gate-to-gate batch mode (i.e., non-real time) traffic levels.
- For technical reasons, the departures and arrivals are to be considered at the same airport.
- Pilot error and read back-error concepts will be clearly defined during the test plan.
- NASA plans to use real-world “best-practices” flight deck roles and responsibilities.

Appendix B: Scenario Descriptions

Section B.1 of this Appendix defines the scenario by Display Type, Communication Modality, and Phase of Flight. Section B.2 contains a description and the taxi route for the arrival scenarios, and Section B.3 a description and the taxi route for the departure scenarios.

B.1 Scenario Case Number by Display Type, Communication, and Flight Phase

Table 38. Scenario Case Number by Display Type and Communication Modality

Display Type	Comm	Phase	Rep	Scenario	ATIS	Phase	Case	Fig
Paper	Voice	Arrival	1	NW3A	A	Data	101	32
Paper	Voice	Arrival	2	NW3A	A	Data	102	32
Paper	Voice	Departure	1	RW27A	J	Data	141	33
Paper	Voice	Departure	2	RW27A	J	Data	142	33
Paper	Voice	Departure	1	RW27C	J	Trng	181	33
Paper	Data Comm	Arrival	1	SC4A	D/E	Data	211	30
Paper	Data Comm	Arrival	2	SC4A	D/E	Data	212	30
Paper	Data Comm	Departure	1	RW33LA	H	Data	251	35
Paper	Data Comm	Departure	2	RW33LA	H	Data	252	35
Paper	Data Comm	Departure	1	RW33LC	H	Trng	281	35
MMD	Data Comm	Arrival	1	NW3B	B/C	Data	321	32
MMD	Data Comm	Arrival	2	NW3B	B/C	Data	322	32
MMD	Data Comm	Departure	1	RW27B	I	Data	361	34
MMD	Data Comm	Departure	2	RW27B	I	Data	362	34
MMD	Data Comm	Arrival	1	SC4C	F/G	Trng	381	33
MMD + Route	Data Comm	Arrival	1	SC4B	F/G	Data	431	33
MMD + Route	Data Comm	Arrival	2	SC4B	F/G	Data	432	33
MMD + Route	Data Comm	Departure	1	RW33LB	K	Data	471	36
MMD + Route	Data Comm	Departure	2	RW33LB	K	Data	472	36
MMD + Route	Data Comm	Arrival	1	NW3C	B/M	Trng (Last)	581	34
MMD	Data Comm	Departure	1	RW27T	N/O	Data (Last)	561	35

Scenario Legend:

NW3A	NORWICH THREE Arrival A, ILS Runway 33L Approach
NW3B	NORWICH THREE Arrival B, ILS Runway 33L Approach
NW3C	NORWICH THREE Arrival C, ILS Runway 33L Approach (Training)
SC4A	SCUPP FOUR Arrival A, ILS Runway 27 Approach
SC4B	SCUPP FOUR Arrival B, ILS Runway 27 Approach
SC4C	SCUPP FOUR Arrival C, ILS Runway 27 Approach (Training)
RW27A	Runway 27 Departure A
RW27B	Runway 27 Departure B
RW27C	Runway 27 Departure C (Training)
RW33LA	Runway 33L Departure A
RW33LB	Runway 33L Departure B
RW33LC	Runway 33L Departure C (Training)

Case Legend:

1st Digit – Cell

1: Paper / Voice
2: Paper / Data Comm
3: MMD / Data Comm
4: MMD+Route / Data Comm
5: Trust (was an arrival MMD / Data Comm scenario)

2nd Digit – Type

0: Arrival, Paper / Voice (S1 Baseline)
1: Arrival, Paper / Data Comm (S1, S2 Baseline)
2: Arrival, MMD / Data Comm (S2)
3: Arrival, MMD+Route / Data Comm (S2)
4: Departure, Paper / Voice (S1 Baseline)
5: Departure, Paper / Data Comm (S1, S2 Baseline)
6: Departure, MMD / Data Comm (S2)
7: Departure, MMD+Route / Data Comm (S2)
8: Training

3rd Digit – Replication Number (1 or 2)

Table 39. Scenario run order by crew

Crew → **Run # ↓**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	101	431 H	141	471	251	361	211 M	321 M	251	101	251
2	251	361	211 H	321 H	431 L	101	471	141	321 L	431 M	431 L
3	321 H	211 L	361	251	141	471	101	431 H	471	361	141
4	471	141	431 M	101	321 M	211 M	361	251	211 H	141	321 M
5	141	471	101	431 M	211 H	321 L	251	361	141	211 L	211 H
6	211 M	321 M	251	361	471	141	431 L	101	361	471	471
7	361	251	321 L	211 L	101	431 H	141	471	431 M	321 H	101
8	431 L	101	471	141	361	251	321 H	211 L	101	251	361
9	102	432 H	142	472	252	362	212 M	322 M	252	102	252
10	252	362	212 H	322 H	432 L	102	472	142	322 L	432 M	432 L
11	322 H	212 L	362	252	142	472	102	432 H	472	362	142
12	472	142	432 M	102	322 M	212 M	362	252	212 H	142	322 M
13	142	472	102	432 M	212 H	322 L	252	362	142	212 L	212 H
14	212 M	322 M	252	362	472	142	432 L	102	362	472	472
15	362	252	322 L	212 L	102	432 H	142	472	432 M	322 H	102
16	432 L	102	472	142	362	252	322 H	212 L	102	252	362

NOTE: Suffix indicates altitude range that the Data Comm messages were given at.

- H: 16,000 – 14,000 feet MSL
- M: 10,000 – 8,000 feet MSL
- L: 7,000 – 5,000 feet MSL

B.2 Taxi Routes for Arrival Scenarios

<u>SCUPP 4 Arrival to Runway 27, Arrival A</u> (Case #211, 212)

Description: Landing Runway 27 (aircraft can exit at taxiways E, K, & M)
Data Comm message: Taxi Terminal B via M.K.E.

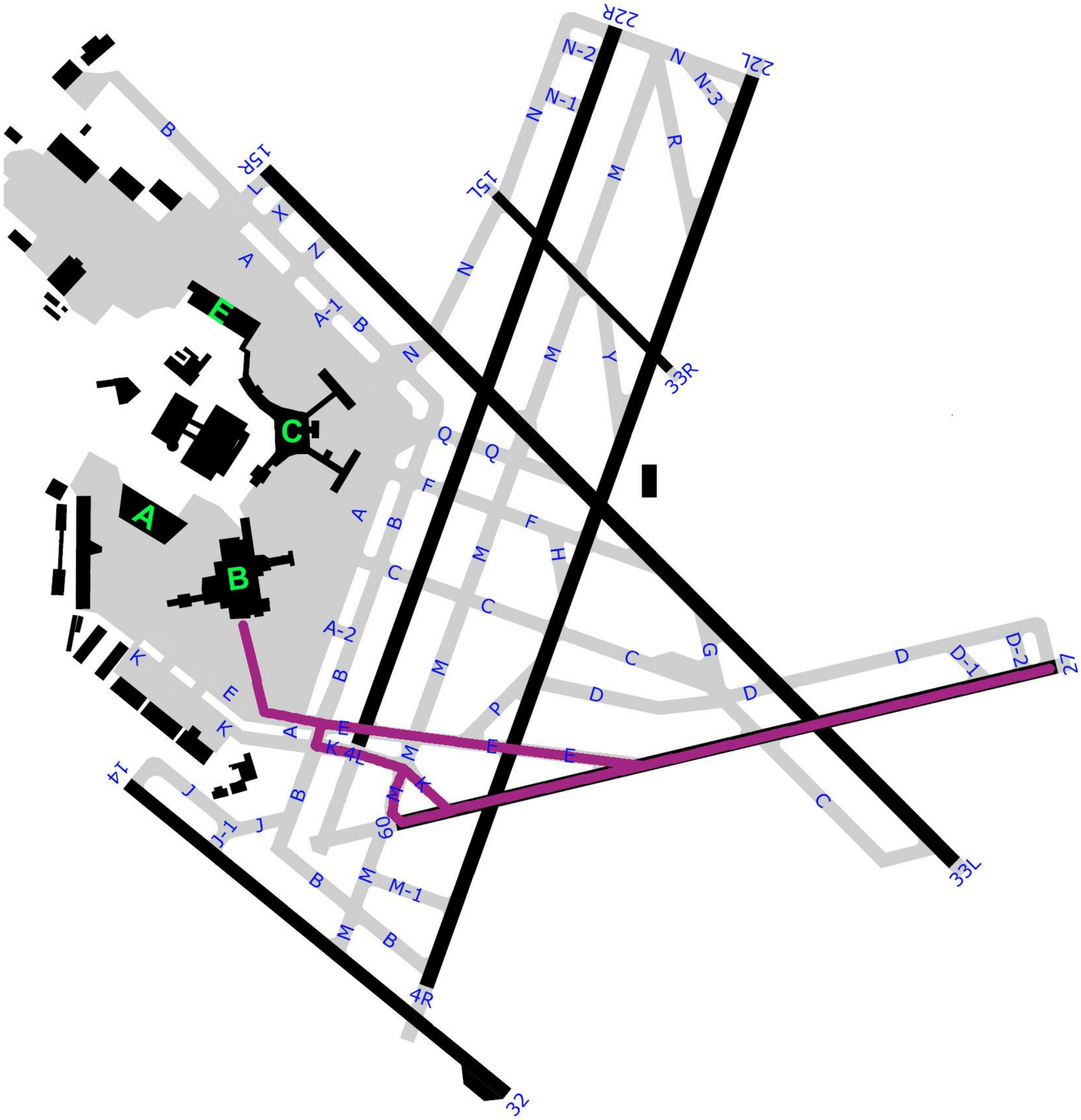


Figure 35. Runway 27 Arrival A

SCUPP4 Arrival to Runway 27, Arrival B and Arrival C (Case #431, 432, and #381)

Description: Landing Runway 27 (aircraft can exit at taxiways E, K, & M)
Data Comm message: Taxi Terminal B via K.A.

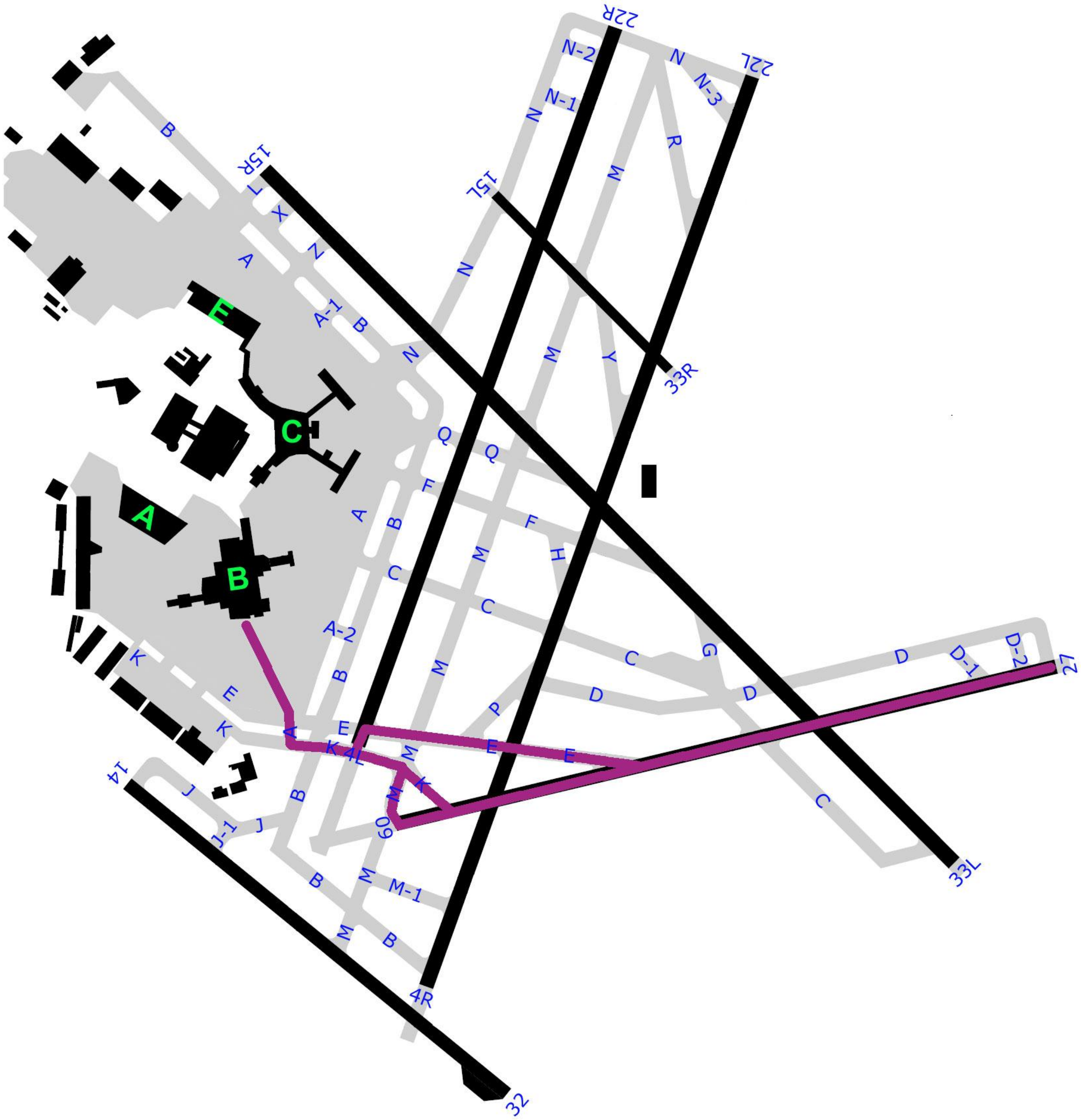


Figure 36. Runway 27 Arrival B and C

NORWICH3 Arrival to Runway 33L Arrival A, B, and C (Case #101, 102, 321, 322, and #581)

Description: Landing Runway 33L (aircraft can exit at taxiways Q, N, Z, X, & L)
Data Comm message: Taxi Terminal E via B.A1.

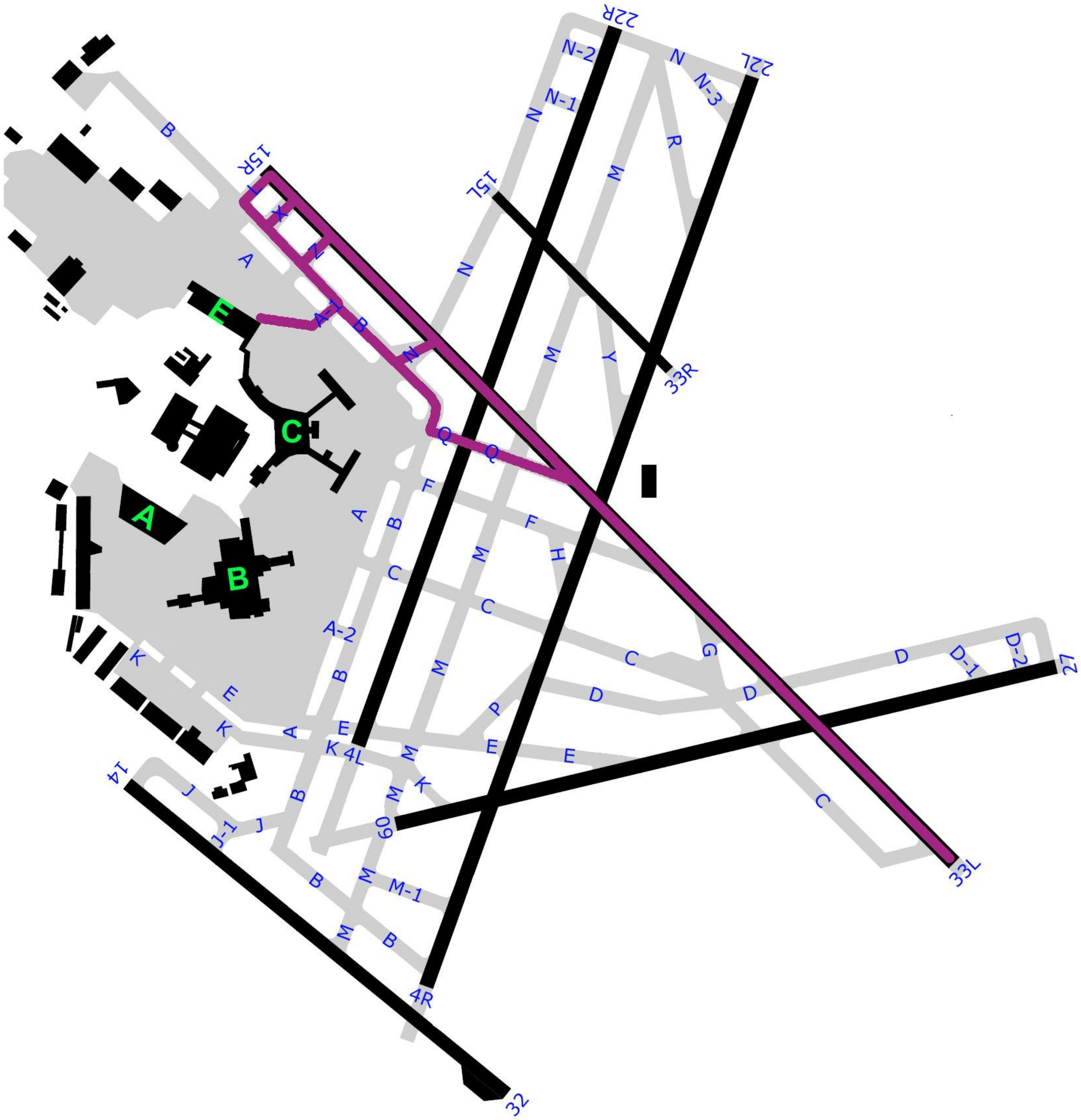


Figure 37. Runway 33L Arrival A, B, and C

B.3 Taxi Routes for Departure Scenarios

Runway 27 Departure A, C, and T (Case #141, 142, 181, and 561)

Description: From Terminal E to Runway 27
Data Comm message: Taxi via A.C.D; Hold short 33L

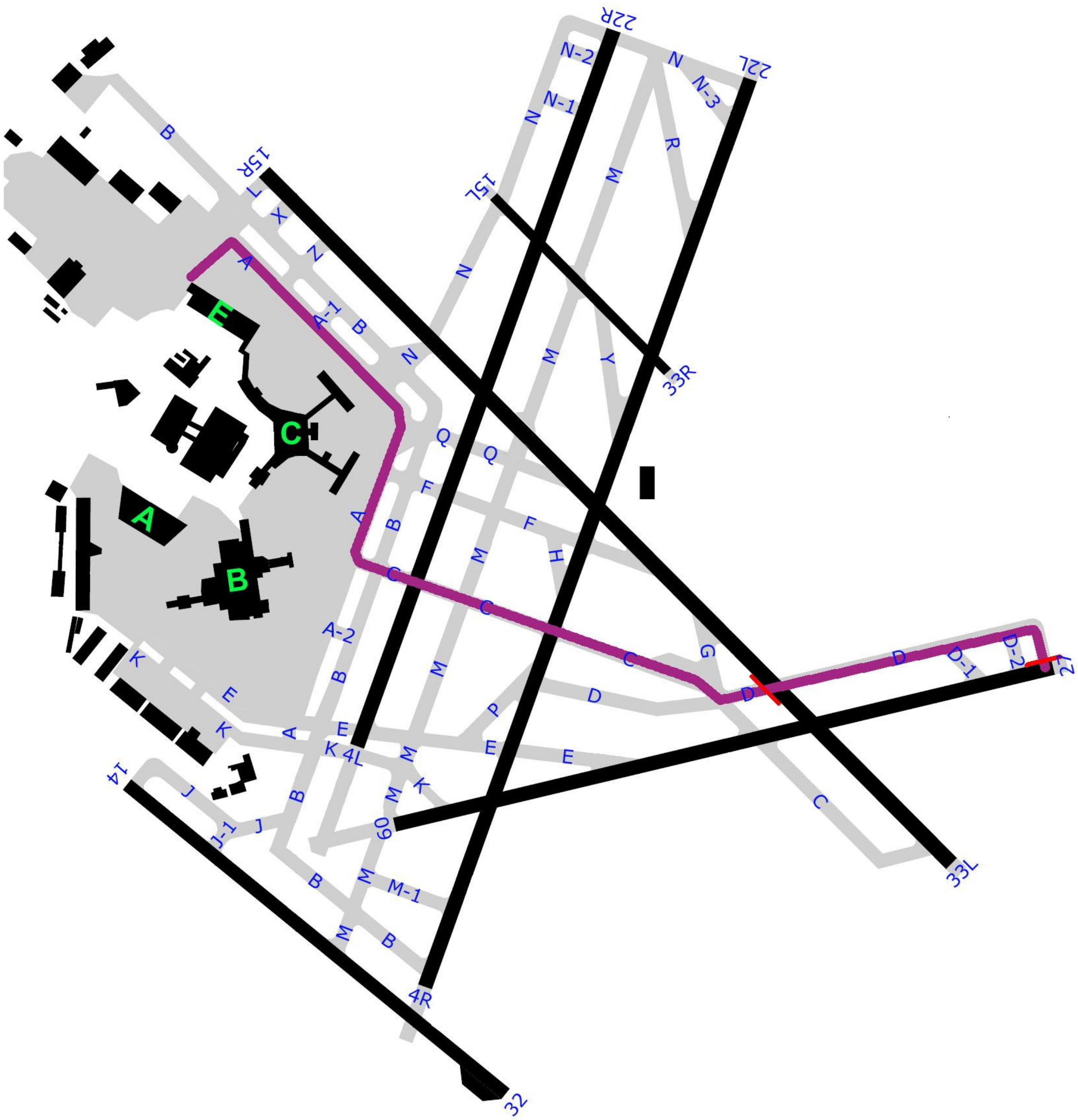


Figure 38. Runway 27 Departure A, C, and T

Runway 27 Departure B (Case #361, 362)

Description: From Terminal E to Runway 27
Data Comm message: Taxi via A.F.H.RW22L.C.D; Hold short 33L

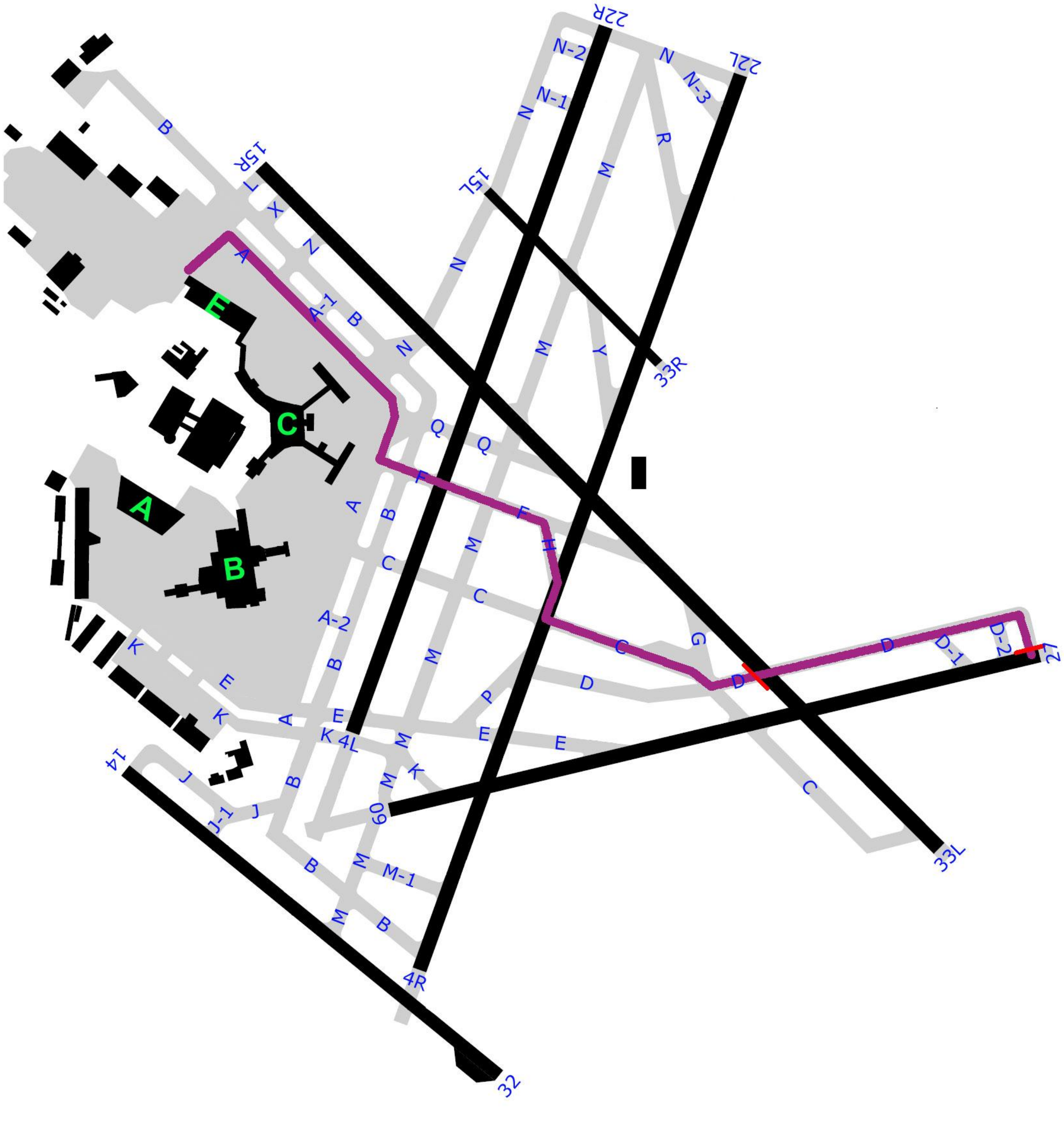


Figure 39. Runway 27 Departure B

<u>Runway 33L Departure A and C</u> (Case #251, 252, and 281)

Description: From Terminal E to Runway 33L:
Data Comm message: Taxi via A.C; Hold short 27

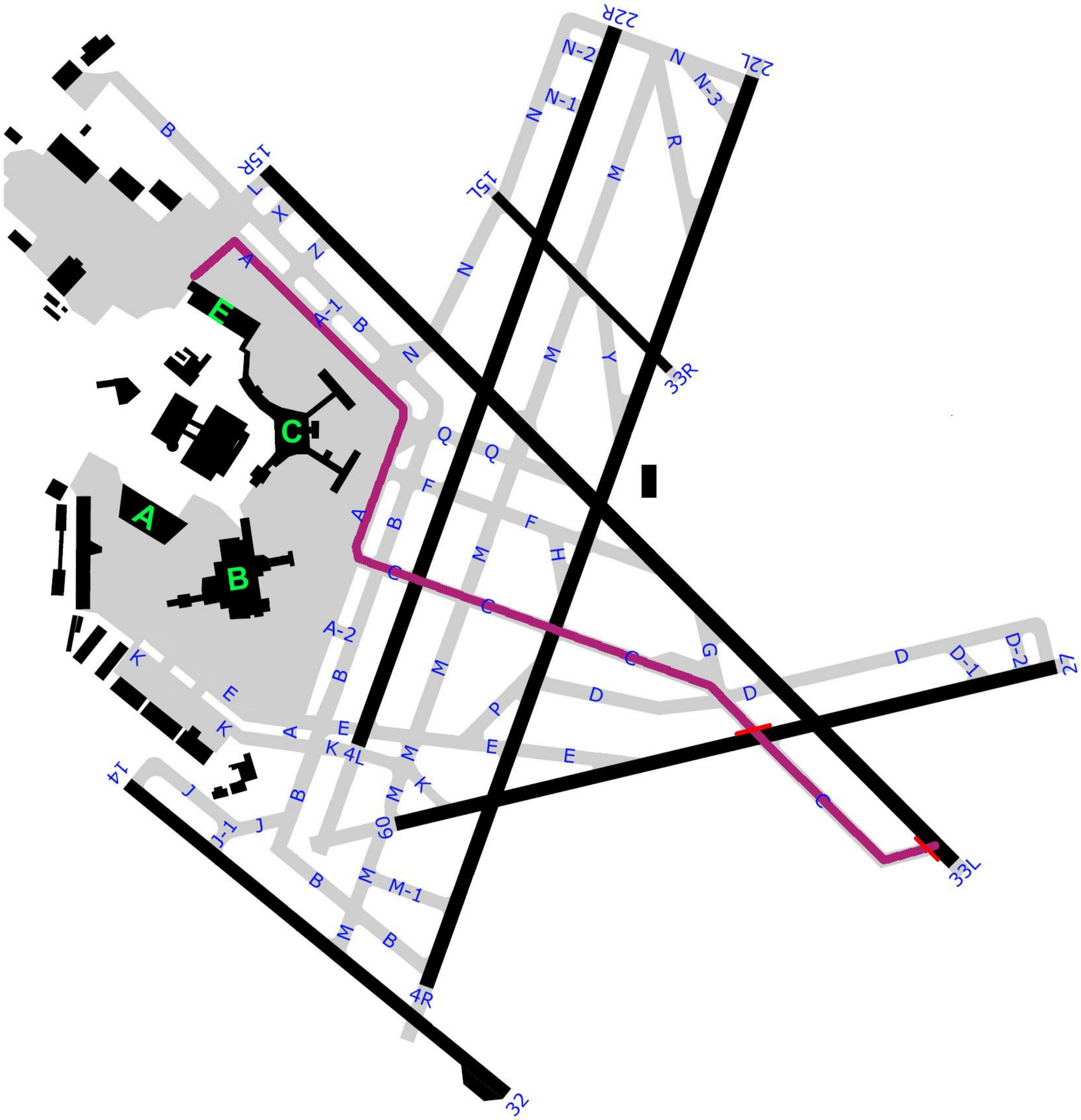


Figure 40. Runway 33L Departure A and C

Runway 33L Departure B (Case #471, 472)

Description: From Terminal E to Runway 33L
Data Comm message: Taxi via A.F.H.RW22L.C; Hold short 27.

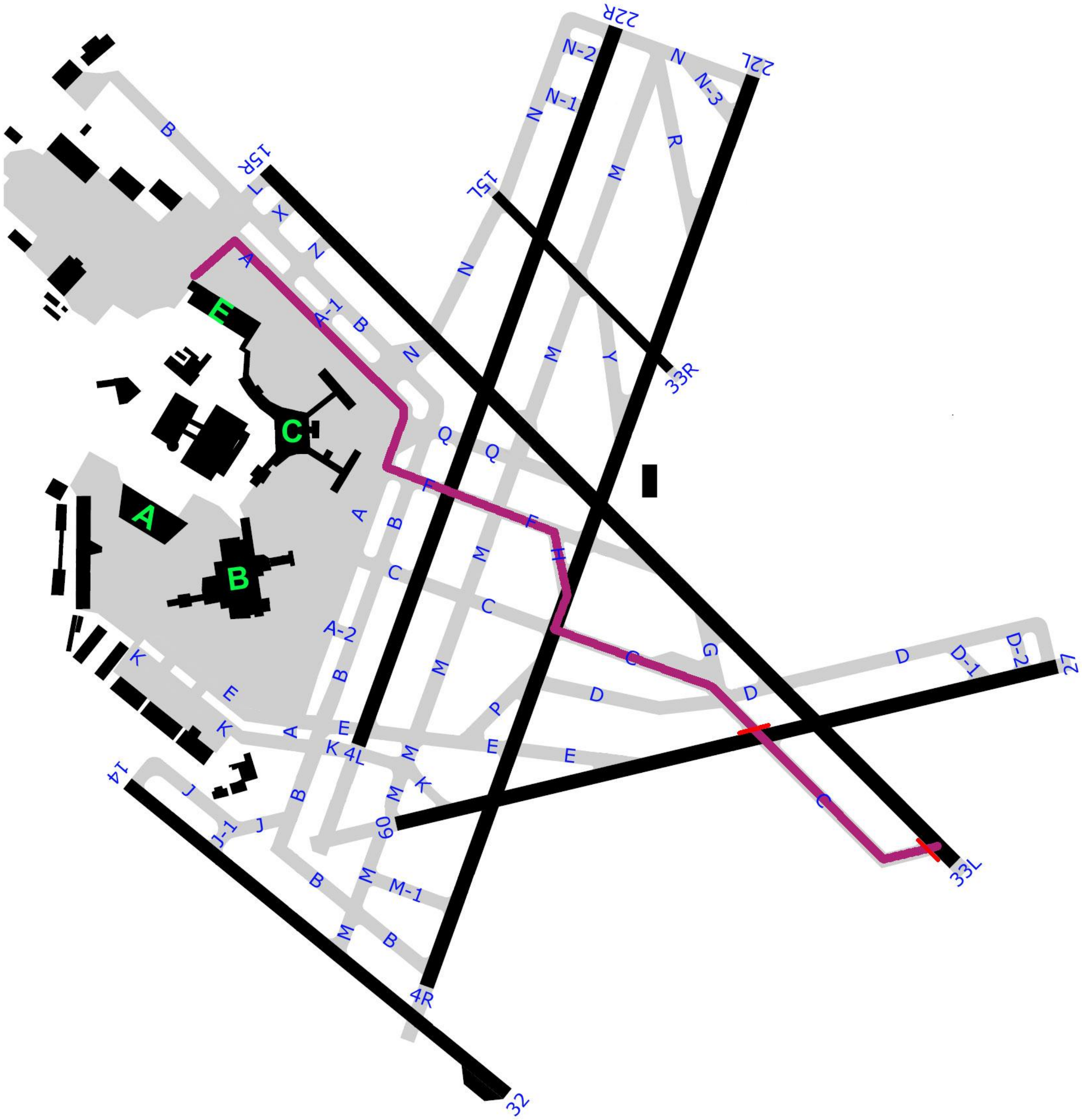


Figure 41. Runway 33L Departure B

Appendix C: Biographical Questionnaire

Appendix C is an exact copy of the Biographical Questionnaire completed by the subject pilots.

This questionnaire requests the most up to date information about the Subject Pilot. This data may be used during data analysis, however, no personal information will be connected to any of the data recorded in this simulation.

Age		____________
Gender (please circle)	MALE	FEMALE
Commercial aircraft type / hours	____________	____________
Military aircraft type / hours	____________	____________
Total flight hours / total simulator hours	____________	____________
Date of last flight (airline transport)		____________
Will you wear glasses during this experiment?		YES NO
Have you had eye surgery? (Please describe your surgery below)		YES NO
Do you have any known eye or eyelid abnormalities (astigmatism, etc)? (Describe)		YES NO
Are your eyes corrected to different distances? (Describe)		YES NO
Do you have experience using Data Comm equipment and procedures? (Describe)		YES NO
How often have you flown into and out of Boston Logan airport in the past five years?		______

Appendix D: Post-Scenario Questionnaire

Appendix D contains all the questions in the Post-Scenario Questionnaire completed by the subject pilots on a Tablet PC (personal computer) after the last training run, and after every data collection run.

D.1 Workload During Scenario by Phase of Flight

Using the chart below, read the descriptions that define a particular workload level during a particular phase of flight or during ground operations. Move vertically up the scale until you find a description that accurately portrays the level of workload based on the scenario you have just flown. Move to the right and read the choices. Below the chart, record the appropriate ratings associated with receiving messages on the <u>specified phase of flight</u> from 1 to 10, 1 being lowest and 10 being the highest workload. If the scenario is a departure there will only be one question to rate. (NOTE: the entire scale was visible to the subject pilot while answering the workload rating questions, and the training package as well as instructions throughout the experiment specified the workload pertained to all normal PF or PM duties and functions, not just those related to Data Comm or flying the aircraft.)

<u>Workload by Phase of Flight</u>

1) Your workload in flight __________ (1-10)

2) Your workload during surface / taxi operations __________ (1-10)

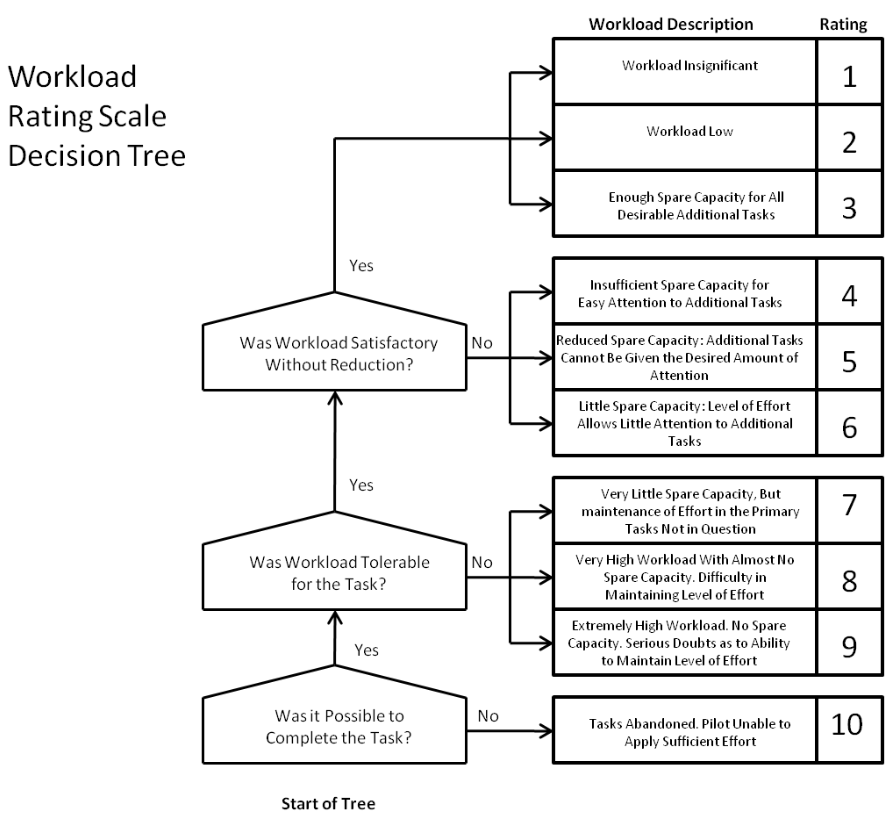


Figure 42. Bedford work scale

D.2 Situation Awareness by Phase of Flight

Please answer the questions below with respect to the impact of Voice or Data Communications between the controller and pilot during the scenario. Select the rating that reflects your understanding of the dimensions described at the left for the appropriate phase of flight (all phases for the arrival scenarios, and surface operations only for the departure scenarios).

DEMAND ON ATTENTIONAL RESOURCES: Rate your overall impression of the scenario in terms of how much attention and effort was required to successfully perform the tasks. Items to consider include: the likelihood of the situation changing suddenly, the degree of complexity associated with this scenario; and the number of variables changing during the scenario.	(1) High Low (7) 2A) 1 2 3 4 5 6 7 during flight 2B) 1 2 3 4 5 6 7 surface ops
SUPPLY OF ATTENTIONAL RESOURCES: Rate the degree of spare attention that you had available to perform tasks other than your primary task of piloting the aircraft was performed. Items to consider include: how much focus and concentration was necessary and how you divided your attention between the flying task and other tasks. High = plenty of spare capacity; Low = little spare capacity..	(1) High Low (7) 2C) 1 2 3 4 5 6 7 during flight 2D) 1 2 3 4 5 6 7 surface ops
UNDERSTANDING OF THE SITUATION: Rate your overall understanding of what was happening with the aircraft during this scenario. Items to consider include: the quantity of information received and understood; the quality of the information; and the familiarity you may have had with what was taking place during the scenario.	(1) High Low (7) 2E) 1 2 3 4 5 6 7 during flight 2F) 1 2 3 4 5 6 7 surface ops

D.3 Sources of Information

Please rate the following with "1" as Very Important, and "7" as Not Important, areas that contributed to your Situation Awareness given all available resources in the flight test scenario. Place an "X" by those areas that did not contribute to your SA.

1. Visual information on the Primary Flight Display
2. Visual perception on the NAV Display
3. Visual information on the charts
4. Visual information available out the window
5. Visual information on the CDU pages
6. Visual information that your crew member directed your attention to
7. Auditory information conveyed by ATC
8. Auditory information conveyed by your crew member
9. Your perception of your crew member's actions

D.4 Crew Interaction

1) Your performance was proficient in this scenario.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7
2) My crewmember's performance was proficient in this scenario.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7
3) Your awareness of operational plans, decisions, and had appropriate SA throughout the flight.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7
4) The other pilot was aware of operational plans, decisions, and had appropriate SA throughout the flight.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7
5) There was adequate communication.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7
6) The Captain and FO maintained their roles throughout the scenario.	(1) Strongly Agree, (7) Strongly Disagree |____|____|____|____|____|____| 1 7

D.5 Acceptability of "Expected Taxi" and "Taxi" Clearances

1) Did the display of the OWNSHIP POSITION on the navigation display make the taxi clearance easier to understand and to carry out? [NA for runs without ownship displayed] | | | | | | | instructions were easier to understand — sometimes easier to understand — did not make easier to understand	N/A ____
2) Did the display of the ROUTE on the navigation display make the taxi clearance easier to understand and to carry out? [NA for runs without route displayed] | | | | | | | instructions were easier to understand — sometimes easier to understand — did not make easier to understand	N/A ____
3) Did you have confidence that the taxi route was accurately depicted based on the Data Comm ATC instruction? | | | | | | | confident the taxi route was accurate & followed the route — confident route accurate but verified the route — not confident taxi route displayed accurately	
4) Did you have a sufficient amount of time to respond to the Voice or Data Comm transmitted messages? | | | | | | | I had more than enough time to respond — just about the right amount of time — I did not have enough time to respond	
5) Was the amount of Head Down time required to receive and respond to just the "Expected Taxi" Data Comm messages acceptable in this scenario? | | | | | | | Minimal increase in Head Down time — Acceptable amount of Head Down time — Too much head down time	
6) Was the amount of heads-down time required to receive and respond to other non-time critical Data Comm messages acceptable in this scenario? (e.g., frequency changes, new altimeter setting, etc) | | | | | | | Minimal increase in Head Down time — Acceptable amount of Head Down time — Too much heads down time	
7) Overall, was the communication mode (Voice or Data Comm) for receiving Expected Taxi and Taxi clearances acceptable during this scenario? (Include consideration of message intrusiveness, amount of heads-down time required, effect of party line information, expected response and timing of the response, ease of use, etc.) | | | | | | | Completely acceptable — Neither unacceptable nor acceptable — Completely unacceptable	
8) How much operational risk was introduced by the communication mode (Voice or Data Comm) used during this scenario? | | | | | | | extremely low risk — neither high or low risk — extremely high risk	
9) Was there a point at which you did not feel that the transmitted taxi instructions were accurate? | | | | | | | the message was accurate — some aspects were inaccurate or in question — I did not feel the message was accurate	

Appendix E: Post-Experiment Questionnaire

E.1 Workload Comparison

Considering all the scenarios in this simulation, compare the perceived workload of the scenario type on the left side of the scale to that of the other scenario type at the right end of the scale. Please circle a tick mark at the level of workload considering the impact the communication mode and display had on your task execution and completion (consider time to write down or read the clearance, understand the clearance, upload the clearance if applicable, brief the other crewmember, and then respond to ATC).

<table>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with paper displays</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with Moving Map Display</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
<tr><td>Data Comm with paper displays</td><td></td><td>Data Comm with Moving Map Display</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
<tr><td>Data Comm with paper displays</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
<tr><td>Data Comm with MMD</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>Least workload</td><td>Equal workload</td><td>Least workload</td></tr>
</table>

E.2 Situation Awareness Comparison

Considering all the scenarios in this simulation, compare the perceived SA of the scenario type on the left side of the scale to that of the other scenario type at the right end of the scale. Please circle a tick mark at the level of SA considering the impact the communication mode and display had on your task execution and completion (consider time to write down or read the clearance, understand the clearance, upload the clearance if applicable, brief the other crewmember, and then respond to ATC).

<table>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with paper displays</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with Moving Map Display</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
<tr><td>Voice with paper displays</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
<tr><td>Data Comm with paper displays</td><td></td><td>Data Comm with Moving Map Display</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
<tr><td>Data Comm with paper displays</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
<tr><td>Data Comm with MMD</td><td></td><td>Data Comm with MMD and route</td></tr>
<tr><td>| |</td><td>| | |</td><td>| |</td></tr>
<tr><td>High SA</td><td>Equal SA</td><td>High SA</td></tr>
</table>

E.3 Acceptability of "Expected Taxi" Data Comm message

Please mark the appropriate boxes to indicate:

- when it would be acceptable for a controller to send an Expected Taxi clearance via Data Comm (for planning purposes, an immediate response is not required, etc)
- when the flight crew would respond to the Expected Taxi message (within 2 minutes):

	Controller to send Expected Taxi msg		Flight crew to respond to message	
	YES	NO	YES	NO
Condition: Data Comm with paper				
Above 10,000 feet MSL				
Below 10,000 feet MSL				
Final Approach Fix through roll-out				
Taxiing Surface Operations				
Condition: Data Comm with Moving Map				
Above 10,000 feet MSL				
Below 10,000 feet MSL				
Final Approach Fix through roll-out				
Taxiing Surface Operations				
Condition: Data Comm with MMD and route				
Above 10,000 feet MSL				
Below 10,000 feet MSL				
Final Approach Fix through roll-out				
Taxiing Surface Operations				

E.4 Trust in the System

Considering all the scenarios in this simulation, compare your perceived trust of the system as it pertains to the communication modality or display configuration on the left side of the scale to that of the other communication modality or display configuration at the right end of the scale. Please circle a tick mark at the level of trust in the system considering the impact the communication mode and/or display had on your task execution and completion (consider time to write down or read the clearance, understand the clearance, upload the clearance if applicable, brief the other crewmember, and then respond to ATC).

Voice with paper displays							Data Comm with paper displays
|	|	|	|	|	|	|	
High Trust							High Trust

Voice with paper displays High Trust	Data Comm with Moving Map Display High Trust
Voice with paper displays High Trust	Data Comm with MMD and route High Trust
Data Comm with paper displays High Trust	Data Comm with Moving Map Display High Trust
Data Comm with paper displays High Trust	Data Comm with MMD and route High Trust
Data Comm with MMD High Trust	Data Comm with MMD and route High Trust

On a scale of 1 to 7 by circling a mark along the scale, with 1 being the highest and 7 being the lowest, please rate the next five questions based on your experience here in the experiment.

1. Overall, how confident were you that the data linked message was properly loaded into the FMS and then correctly displayed graphically on the Navigation Display? 1 (Complete confidence) 7 (No Confidence)

2. How often did you verify the accuracy of the data link taxi instructions? 1 (All the time) 7(None of the time)

   If you didn't verify the accuracy, why not (please check those that apply):
   ___ Not enough time
   ___ presumed accurate
   ___ presumed other crew member verified
   ___ Other, please explain.

3. How often did you verify the taxi route displayed on the Navigation Display with the Data Comm message on the CDU? 1 (All the time) 7 (None of the time)

   If you didn't verify the route described by the instructions , why not (check those that apply):
   ___ Not enough time
   ___ presumed accurate
   ___ presumed other crew member verified
   ___ Other, please explain.

4. How long did it take you to notice the data link message was incorrect? 1 (Immediately) 7 (Did not notice)

5. The method for receiving, uploading, and carrying out the air traffic taxi instructions via Data Comm: Has Integrity, Is Reliable, Is incomplete, Is ambiguous ? 1 (No) 7 (Yes)

E.5 Crew Coordination Support

Considering all the scenarios in this simulation, compare the perceived support for effective Crew Resource Management and Crew Coordination of the scenario type on the left side of the scale to that of the other scenario type at the right end of the scale. Please circle a tick mark on the scale index that reflects the effect the communication mode and display had on your ability to effectively coordinate as a team, distribute your attentional resources effectively, and ensure common situation awareness.

Voice with paper displays High SA	| | | | | | | Equal SA	Data Comm with paper displays High SA
Voice with paper displays High SA	| | | | | | | Equal SA	Data Comm with Moving Map Display High SA
Voice with paper displays High SA	| | | | | | | Equal SA	Data Comm with MMD and route High SA
Data Comm with paper displays High SA	| | | | | | | Equal SA	Data Comm with Moving Map Display High SA
Data Comm with paper displays High SA	| | | | | | | Equal SA	Data Comm with MMD and route High SA
Data Comm with MMD High SA	| | | | | | | Equal SA	Data Comm with MMD and route High SA

E.6 Summary

1. To what degree did the scenarios in this experiment accurately simulate a complex, high-workload environment? If not, what was missing? 1 (realistic) 7 (unrealistic)
2. What is your overall assessment of the potential of communicating clearance updates or changes using datalink while an aircraft is taxiing or in busy terminal airspace? 1 (realistic) 7 (unrealistic)
3. Should the dotted cyan lines for an "Expected Taxi" clearance include red hold short bars?
4. Will the solid magenta line for a Taxi clearance on the Navigation Display encourage crew members to begin taxiing prior to receiving the Voice message from ATC?
5. Was the simultaneous Voice and Data Comm instructions to cross an active runway clear? Was there a delay in the FO updating the graphical display on the ND? Was that delay important?
6. How would CDTI (Cockpit Display of Traffic Information) impact your workload, SA, and acceptability of using Data Comm messages in terminal airspace or surface operations?
7. Was the use of Voice by the controller for critical or time-sensitive information (such as crossing the runway) appropriate and necessary?
8. Were there any challenges with Data Comm unique to your flight duties as the PF or PM?
9. Do you have any other comments? Include any unexpected events, operational issues, and any problems with the simulator that affected your performance.

Appendix F: Oculometer Apparatus

A ten-camera oculometer system was installed in the IFD to support unobtrusive collection of eye tracking and head position data for both flight crew subjects. The Smart Eye Inc. eye tracker used in this experiment (Figure 43) was a remote eye tracking system that used facial recognition to calculate the position of defined points on a subjects head relative to the calibrated position of two or more cameras. The cameras used the facial features to locate the corners of each of the subject's eyes and digitally zoomed to enhance the image of the eye.

Figure 43. Oculometer and IR Flasher

To calculate eye gaze vectors from the head origin, infrared light emitting diodes projected infrared light to illuminate the pilots face and to create two ocular reflections; a static corneal reflection and a pupil reflection that moves in conjunction with eye movements. Triangulating the angular difference between the corneal reflection and pupil reflection, the Smart Eye eye tracking system creates a vector between the two points, which creates an eye gaze vector originating from the corneal reflection at the center of the pilot's eyes (Figure 44).

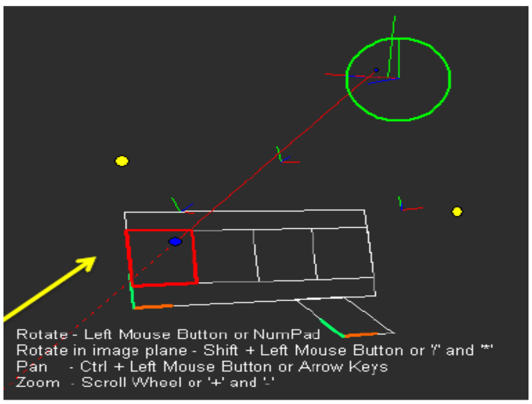


Figure 44. Eye Gaze Vector

Ten cameras in total were utilized, with one eye tracking system for the PF and one for the PM, each with five cameras to capture the gaze vectors of both pilots simultaneously (installation shown in Figure 45). To synchronize the systems, Smart Eye Inc. created a modified eye tracking system network, tethering two systems together using a master-slave relationship. Each system is time stamped synchronously with global positioning system time so eye gaze vector data from both pilots can be compared.

In order to achieve robust eye tracking data over the span of coverage required for normal cockpit operations, the system had to be capable of covering +/-45 degrees of center, and +10 degrees from horizon and to the base of the CDU for each pilot. This requirement had to be met while still maintaining a high level of simulator fidelity by making the cameras as inconspicuous as possible on the flight deck. Camera placement was optimized for coverage within constraints imposed by limited available real estate.

To test which available locations for installation on the flight deck provided the greatest coverage capability, a mockup of the IFD was created. Test results concluded with five locations per side being chosen (mirrored locations between left and right seat) that yielded sufficient coverage to perform flight testing while remaining minimally obtrusive in the flight deck. System spatial accuracy was tested to be no greater than 2 degrees gaze angle for any calibration point on the display panels.

The oculometer provided the following raw data in real-time:

- Gaze vectors for each eye of both crew members (raw)
- Head and eye position (each eye) for each crew
- Eyelid closure distance for each eye for each crew
- Pupil size for each eye for each crew

Figure 45. Location of Oculometers and IR Flashers in IFD Simulator

Appendix G: Data Comm Message Format

Appendix G lists all the Data Comm Uplink and Downlink message IDs and formats used in this research, and were based on the proposed revision to the Data Comm standards (Reference 33), or developed specifically for this experiment (marked as "New").

NOTE 1: No standard yet for taxi messages, therefore followed NASA Langley and EMMA2 operational evaluation with each taxiway defined by a single letter, e.g., "A" and not "ALPHA".

NOTE 2: All datalink taxi messages provide the route only, and do not constitute direction to begin taxiing, nor permission to cross any active or inactive runway (movement instructions given via voice).

NOTE 3: No yet defined if Taxi Clearance is from current position to takeoff runway or parking location, to include segments after crossing a runway.

NOTE 4: Data Comm uplink CDU displayable characters need to be restricted to uppercase alpha characters A - Z; numerical numbers 0 - 9; space ( ); and symbols (,) (.) (/) (+) (-).

Table 40. Data Comm uplink messages (UM) and downlink messages (DM)

UM 0, 1, 3, 4, 5	General Responses.	UNABLE, STANDBY, ROGER, AFFIRM, NEGATIVE
UM DT01 (New)	Instruction that engine start up is approved at the specified time.	START UP APPROVED [assigned time]
UM DT03 (New)	Instruction that push back is approved at specified location, direction, and time	PUSH BACK APPROVED [pushback information] [assigned time]
UM DT05 (New)	Notification that taxi clearance may be issued on the specified taxi route	EXPECT TAXI [taxi route]
UM DT09 (New)	Instruction to taxi to the specified location without a hold short instruction.	TAXI [*taxi route*]
UM DT10 (New)	Instruction to taxi to the specified location with a hold short position.	RUNWAY [*runway*] TAXI [*taxi route*]
New UM DT12	Instruction to hold the current position.	HOLD POSITION
UM DT73 (New)	Notification to the aircraft of the instructions to be followed from departure until the specified clearance limit.	[departure clearance routing]
UM47	Instruction that the specific position is to be crossed at or above the specified level.	CROSS [position] AT OR ABOVE [level]
UM117	Instruction that the ATS unit with specified ATS name is to be contacted on the specified frequency.	CONTACT [unit name] [frequency]
UM212	ATS advisory that the specified ATIS information at the specified airport is current	[facility designation] ATIS [atis code] CURRENT
UM 213 (New)	ATS advisory that the specified altimeter setting relates to the specified facility.	[facility designation] ALTIMETER [altimeter] [timesec]
DM0, 1, 2, 3, 4, 5, 6	General Responses:	WILCO, UNABLE, STANDBY, ROGER, AFFIRM, NEGATIVE, REQUEST

Appendix H: Data Comm Uplink Messages

Table 41. Data Comm uplink messages by scenario

Case #	***Arrival, Data Comm with Paper***
211	CROSS SCUPP AT 11,000 FT 230 KIAS
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A
211	KBOS ALTIMETER 30.02
211	EXPECT TAXI TO TERMINAL B VIA E
211	KBOS ATIS ECHO CURRENT
211	CONTACT BOS TOWER 132.22
211	TAXI TO TERMINAL B VIA K.E-1
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E
212	CROSS SCUPP AT 11,000 FT 230 KIAS
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A
212	KBOS ALTIMETER 30.02
212	EXPECT TAXI TO TERMINAL B VIA E
212	KBOS ATIS ECHO CURRENT
212	CONTACT BOS TOWER 132.22
212	TAXI TO TERMINAL B VIA K.E-1
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E

Case #	***Departure, Data Comm with Paper***
251	CLEARED TO START
251	KBOS ATIS HOTEL CURRENT
251	PUSHBACK AT 1931Z
251	KBOS ALTIMETER 29.96
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L
252	KBOS ATIS HOTEL CURRENT
252	KBOS ALTIMETER 29.96
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C
252	PUSHBACK AT 1434Z
252	CLEARED TO START
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L

Case #	*Arrival, Data Comm with Moving Map Display (MMD)*
321	CROSS PVD AT 11000 FT 250 KIAS
321	KBOS ALTIMETER 30.02
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1
321	KBOS ATIS CHARLIE CURRENT
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z
321	CONTACT BOS TOWER 128.8
321	TAXI TO TERMINAL E VIA N.B.Z
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A
322	CROSS PVD AT 11000 FT 250 KIAS
322	KBOS ALTIMETER 30.02
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1
322	KBOS ATIS CHARLIE CURRENT
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z
322	CONTACT BOS TOWER 128.8
322	TAXI TO TERMINAL E VIA N.B.Z
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A

Case #	*Departure, Data Comm with Moving Map Display (MMD)*
361	KBOS ATIS INDIA CURRENT
361	KBOS ALTIMETER 29.90
361	EXPECT TAXI TO RW 27 VIA A.C.D
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D
361	PUSHBACK AT 2158Z
361	CLEARED TO START
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27
362	KBOS ATIS INDIA CURRENT
362	KBOS ALTIMETER 29.90
362	EXPECT TAXI TO RW 27 VIA A.C.D
362	PUSHBACK AT 1648Z
362	CLEARED TO START
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27

Case #	Arrival, Data Comm with Moving Map Display and Route
431	CROSS SCUPP AT 11,000 FT 230 KIAS
431	EXPECT TAXI TO TERMINAL B VIA E
431	KBOS ALTIMETER 30.02
431	EXPECT TAXI TO TERMINAL B VIA K.B.E
431	KBOS ATIS GOLF CURRENT
431	CONTACT BOS TOWER 132.22
431	TAXI TO TERMINAL B VIA K.B.A-2
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1
432	CROSS SCUPP AT 11,000 FT 230 KIAS
432	EXPECT TAXI TO TERMINAL B VIA E
432	KBOS ALTIMETER 30.02
432	EXPECT TAXI TO TERMINAL B VIA K.B.E
432	KBOS ATIS GOLF CURRENT
432	CONTACT BOS TOWER 132.22
432	TAXI TO TERMINAL B VIA K.B.A-2
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1

Case #	Departure, Data Comm with Moving Map Display and Route
471	KBOS ATIS KILO CURRENT
471	KBOS ALTIMETER 30.04
471	EXPECT TAXI TO RW 33L VIA A.F.M.C
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C
471	PUSHBACK AT 2033Z
471	CLEARED TO START
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27
471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L
472	KBOS ATIS KILO CURRENT
472	KBOS ALTIMETER 30.04
472	EXPECT TAXI TO RW 33L VIA A.F.M.C
472	PUSHBACK AT 1544Z
472	CLEARED TO START
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L

Appendix I: Flight Crew Training Program

Appendix I contains the slides given to the flight crew during training prior to proceeding to the simulator. The two-hour training program was structured to provide the subject pilots an overview of the NextGen environment by 2017, to include new technologies, new flight procedures, and the challenges in implementing this concept of operations. An experiment hypothesis and test plan was described, and then an in-depth discussion was held on Data Comm messages and required crew interaction, as well as the associated displays. At that point in the training program, tablet PCs were given to both crew members for them to practice the Data Comm messages and responses, as well as to see what the graphical display looked like.

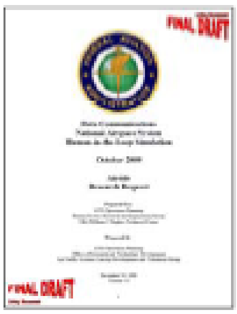
Once all the individual messages were understood and replied to properly, the training shifted to describing each of the eight scenarios in detail, and ensuring that the crews understood what to expect and what was expected of them. The training program finished with practicing how to answer the electronic questionnaires on the tablet PC, and a short description of the oculometer system and how the calibration process worked.

Following the academic portion of the training program, the two crew members were brought to the IFD, where they started with building facial profiles for the oculometer system, then began part-task and differences training in the IFD. This was followed by four training runs which consisted of departure, arrival, departure, and arrival scenarios. For training purposes, and to provide data for one of the two Trust scenarios, the electronic post-scenario questionnaire was completed after the final training run.

National Aeronautics and Space Administration

Welcome to the NASA/FAA Data Communication Airside Human-In-The-Loop Experiment

NASA Langley Research Center
January – March 2010



Current: 8 Feb 2010

Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

2

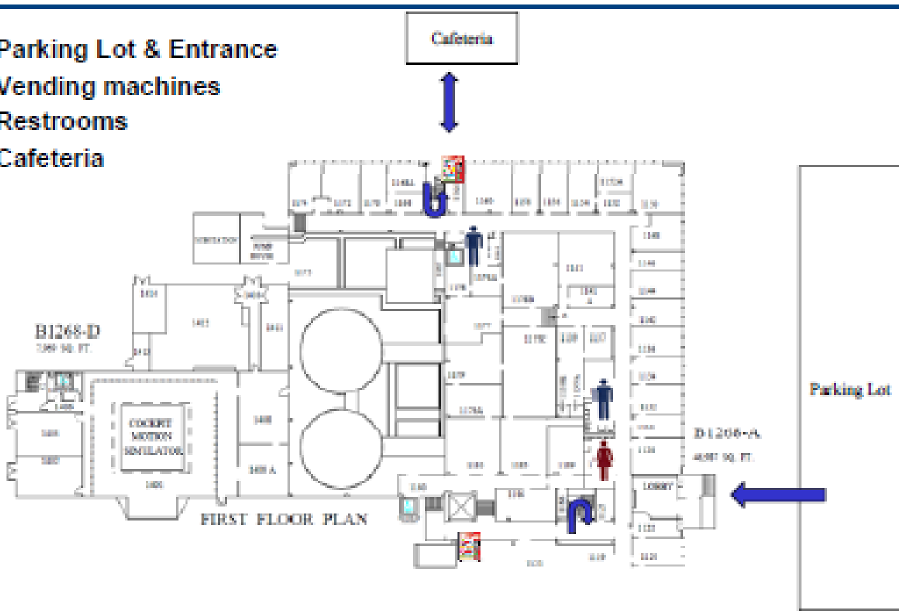
Intro: Admin

- **Cell phones to vibrate or off please.**
  - Off or not in the simulator during data runs
- **Research team members**
  - Mike Norman, Brian Baxley, Cathy Adams, Kara Latorella, Kyle Ellis, Bill Lynn, Dan Burdette, Paul Sugden, Wendy Pifer, Jerry Karwac
- **Restrictions Unique to Experiments:**
  - No discussing opinions about the procedure with each other until after final post-experiment questionnaire and debrief session is complete
  - No discussing the experiment with follow-on subject pilots or anyone else until the experiment is complete (12 March 2010)
- **Informed Consent form**
- **Collect Biographical and NEO-FFI Questionnaires**
- **Lunch options**

3

Intro: 1st Floor Orientation

- Parking Lot & Entrance
- Vending machines
- Restrooms
- Cafeteria



4

Intro: 2nd Floor Orientation

- Briefing Room (BR)
- Integration Flight Deck (IFD)
- Restrooms
- Emergency Exits

5

Intro: Schedule

Day / Time	Event	Location
1 / 0800	Intro Brief and Training	Pilot Briefing Room
1 / 0945	Oculometer Calibration	IFD
1 / 1015	IFD Orientation & Part-Task Training	IFD
1 / 1030	Training Runs T1-T4	IFD
1 / 1230	Lunch	Cafeteria
1 / 1315	Data Runs 1 – 4	IFD
1 / 1505	Break	
1 / 1515	Data Runs 5 – 8	IFD
1 / 1700	End Day 1	
2 / 0800	Data Runs 9 – 12	IFD
2 / 1000	Break	
2 / 1015	Data Runs 13 – 17	IFD
2 / 1300	Post-Experiment Debrief	Pilot Briefing Room
2 / 1400	Experiment Complete	

6

Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

7

FAA Segment 2 (~2017 – 2022)

- Segment Two represents a transition from en-route and tower domains to high-density TRACON and "…automation-assisted strategic management of ATC" and conformance management for trajectory agreements
- Voice communications continue to exist but reserved for tactical, time-critical, and off-nominal operations (failures)
- Terminal area is expected to increase magnitude of findings from en-route research because of increased density of aircraft and coping strategies required for ATC and pilots

8

Data Comm Airside Purpose

- IA1-973, Technical Direction 1
  - Research: collaborative HITL for datalink taxi instructions and when to inhibit datalink communications in Segment 2 ATM environment (~2017 – 2022)
  - Acceptability will be assessed in the context of expected, actual, and amended D-Taxi clearances during surface operations, and expected taxi clearances and other strategic CPDLC messages while on approach.
- **Evaluate the effect of datalink communications modality employment on flight crew workload and situation awareness during arrival, taxi-in and taxi-out operations.**
- **Evaluate the influence of graphical display of airport and ownship route on crew workload and situation awareness in a datalink with voice-by-exception environment.**
- *Not a checkride, not looking for fast/perfect operations*
- *Want data and opinion on when and how to use Data Comm*

9

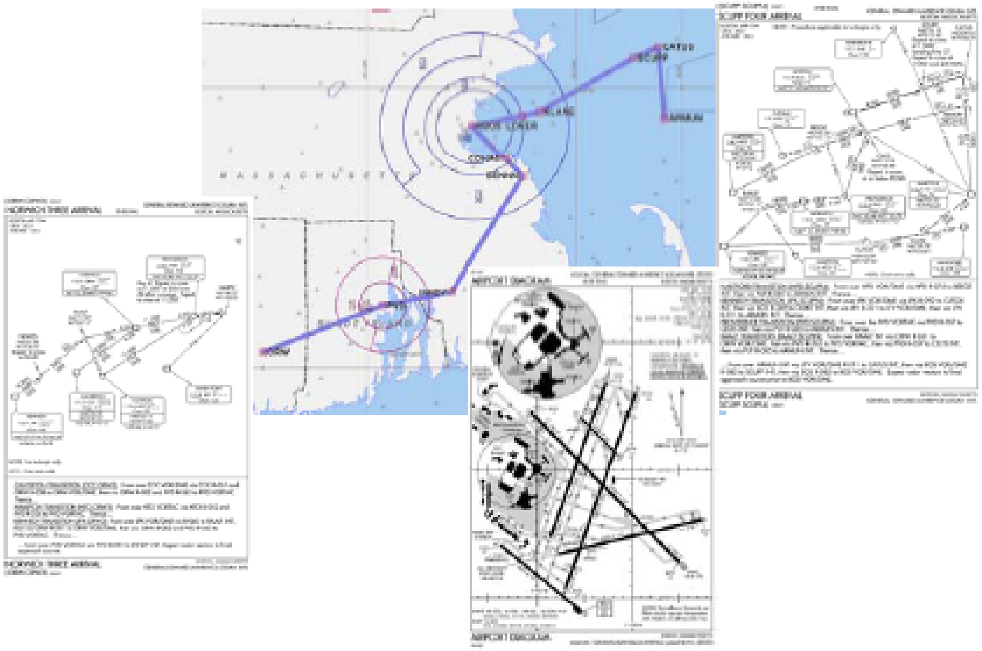
Experiment Test Runs

- High-fidelity simulation of operationally realistic normal operations with high traffic levels, high task load, worst-case
  - Compare typical current Voice scenario to intrusive Data Comm scenario
  - No emergencies or abnormal procedures, however expect operational errors to occur
- Data runs will be distributed among the following eight conditions, and each run will be accomplished twice.

Type	Flight Phase	Comm Mode	Graphical Display		Comm (S1)	Display (S2)
0	Arrival	Voice	None		S1	
1	Arrival	Data Comm	None		S1	S2
2	Arrival	Data Comm	MMD + ownship			S2
3	Arrival	Data Comm	MMD, ownship, route			S2
4	Departure	Voice	None		S1	
5	Departure	Data Comm	None		S1	S2
6	Departure	Data Comm	MMD + ownship			S2
7	Departure	Data Comm	MMD, ownship, route			S2

10

Experiment Environment



11

Voice / Data Comm Protocol

- Respond to Data Comm messages as soon as practicable, consistent with workload priority
  - please use realistic procedures based on safe SOP and CRM
- Respond to communication in same mode; reply to oldest msg first
- Voice communications will always be used in all scenarios for:
  - to begin taxing the aircraft; clearance to cross all runways; off-nominal
- Data Comm messages and loading them into the Moving Map display as graphical routes will be accomplished via the CDU
- Expected D-Taxi messages:
  - given by ATC for crew for planning purposes (taxi brief, descent brief)
  - must be subsequently updated with a Taxi clearance for the actual taxi route
  - crew should acknowledge with ROGER; message will not time out
  - will be given in Data Comm scenarios but not Voice scenarios
  - in departure scenarios will be given prior to crew's request for taxi clearance
  - in arrival scenarios will be varied in altitude / distance from the airport so it's effect on crew workload by phase of the approach can be assessed
    - real-world implementation by 2017 is expected to be 15 minutes prior to push-back for departures, and prior to Top-Of-Descent for arrivals

12

Scenario Assumptions

- Day, VMC operations under Instrument Flight Rules (IFR)
- No emergencies or off-nominal events, however expect operational errors
- Align with current KBOS surface operations and comm when able:
  - Northwest flow, primary Runways are 27 and 33L
  - Runways 22R & 22L are inactive, but used for taxi operations
- Departures are from the gate until in position and holding for takeoff, and arrivals are from Top of Descent through taxi to the terminal gate
- Callsigns:
  - NASA557 always ownship callsign
  - party line callsigns unique in each scenario; some recycled between scenarios
  - party line callsigns align with out the window view of aircraft type & paint

  Auto Pilot, TCAS, and ACARS are inoperative
  - the aircraft will be hand flown (i.e., Autopilot disconnected), however the Autothrottle may be engaged to enable Speed Hold Mode
- Workload and comfort level permitting (to assist scripting of traffic):
  - taxi as soon as possible when cleared by ATC
  - 10 knots on turns and 20 knots on straight-aways
- As realistic and real-world operations into Boston as we can make it
  - checklists, weight changes, speed cards, taxi operations, headsets, etc

13

Experiment Simplifications

- Data Comm messages intended to be straight forward and accurate
- Use left radio control head for ATC, right control head for ATIS
  - ATIS has no time stamp and changes not correlated to real-world clock time
  - ATIS does have an Identifier; crew will be notified if new message is current
  - not available until sim is in OPERATE
- Interaction with Ground Crew for pushback:
  - Captain calls for pushback when ready by talking to researcher (no intercom)
  - researcher initiates pushback from gate, responds with ground crew comm
- Crew will receive final takeoff weight for departure scenarios from the researcher in the form of a card
- Be fully configured and at approach speed by Final Approach Fix

  No party line comm prior to Pushback or on Arrival frequency
- Winds will vary, however not intended to be a factor for this experiment
  - final ATIS or tower call to ownship will have correct wind

14

Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

15

Data Comm messages admin

- Data Comm Uplinks (ATC to crew)
  - During Scenario: ATIS, altimeter, Expected Taxi, Taxi, Amended Taxi
  - Pre-loaded during arrivals: Altitude and speed changes to route
- Data Comm Downlinks (crew to ATC)
  - ROGER if Uplink is informational: Expected Taxi, Altimeter, ATIS
  - WILCO if Uplink is directive: Taxi
  - UNABLE if unable (use Voice communication to resolve)
- Acknowledge all Data Comm Uplink messages when time and workload permits
- Standard Operating Procedures are:
  - PM (First Officer) will brief the message to the PF (Captain)
  - Both agree on response, PM sends Data Comm response
  - Either crew member may load the route on their own Nav Display
- Upper EICAS has "ATC Message" light
  - On whenever there is a Data Comm msg the crew has not replied to

16

Data Comm message types

- **Startup and Pushback**
  - 2 separate Downlinks and 2 separate Uplinks
  - can send one immediately after the other
- **Taxi route**
  - FO requests Taxi Clearance after Startup and checklist complete
  - Uplink is only the taxi route, <u>but not</u> clearance to start moving
    - if a Data Comm scenario: includes hold short instructions, WILCO response
    - if scenario includes route display: dotted white line ending in red hold short bar, dotted white turns to solid magenta line after crew sends WILCO response, route beyond red hold short remains dotted cyan Expected Taxi
  - *ATC voice required to start taxing (no crew call required to initiate)*
- **Expected Taxi route**
  - Ground: prior to crew Downlink request for Taxi route
  - Airborne: 17,000 MSL to 5000' AGL
  - Planning purposes only, therefore:
    - no hold short instructions in message; crew downlinks a ROGER response
    - If scenario includes route on ND: dotted cyan line, and no red hold short bars

17

Data Comm pages

- **Power On**
- **ATC Index**
- **ATC Logon Status**
- **ATC LOG**
- **ATC Request**

– *NOTE: all times based off GMT clock by FO's left knee*

18

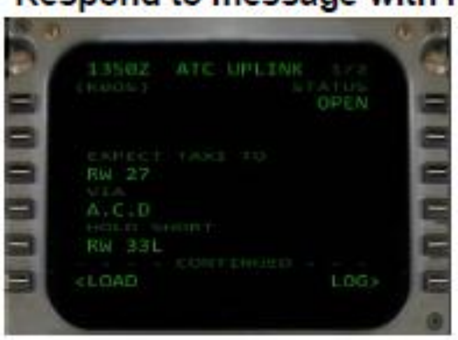
Data Comm: Pushback and Start

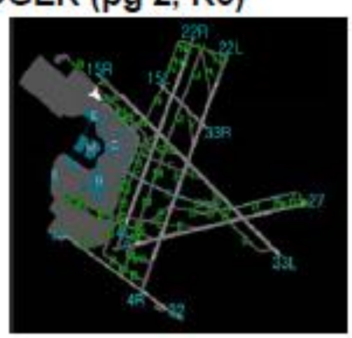
- Two separate requests; second request can be sent prior to receiving response to the first
- Respond to message (pg 2, R5)

19

Data Comm: Expected Taxi

- Sent by ATC:
  - Ground: prior to crew request for Taxi Clearance [15 min prior to start]
  - Airborne: between 17,000' and 5,000' MSL [prior to Top Of Descent]
- First line of message says "EXPECT TAXI TO"
  - For crew planning purposes, either on departure or arrival
  - If graphical display on ND available, PM presses LOAD (pg 1, L6) and route appears as dotted cyan line with no red hold short lines
- Respond to message with ROGER (pg 2, R5)

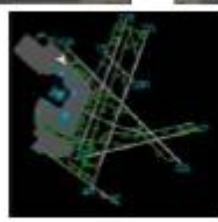


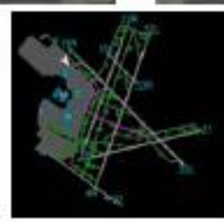


20

Data Comm: Taxi

- **First line of message says "TAXI TO"**
- **Load route to ND if available (pg 1, L6)**
  - only 1 in 4 scenarios; only time the LOAD function is visible (button L6)
    - APRT button must also be depressed to display the route
- **Respond to message with WILCO (pg 2, R5)**



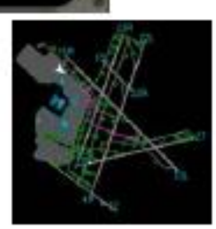


- dotted cyan: expected
- dotted white: proposed
- solid magenta: accepted
- red bar: hold short line

21

Data Comm: Amended Taxi Msg

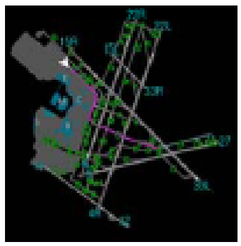
- **First line of message is "AMENDED CLEARANCE"**
- **Load route to ND if available (pg 1, L6)**
  - changes to route show as dotted white
- **Respond to message with WILCO (pg 2, R5)**
  - old magenta line replaced with new route

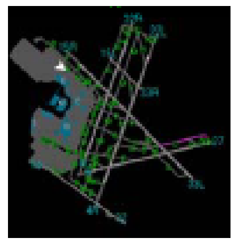


22

Data Comm: Crossing Active Rwy

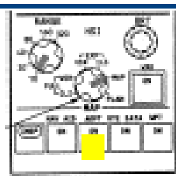
- Ground uses Voice or D/C to send crew to Tower
- Crew checks in on Tower using Voice
- ATC simultaneously issues Voice and Data Comm messages to cross the active Runway
  - Captain immediately starts crossing the runway
  - FO loads route to ND (if available) and WILCOs message (pg 2, R5)
  - prioritize with other cockpit duties (visual lookout, checklists, etc)
- *NOTE*: Voice only to take the active Runway





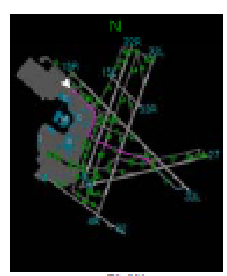
23

Navigation Display on the Surface



- ARPT Button not depressed:
  - Standard MAP & PLAN displays
    - never display taxi routes
  - Range functions standard:
    - Ground: 10, 20, 40, 80, 160, 320
    - *NOTE*: number shown always to range ring / tick
- ARPT Button depressed:
  - MAP: aircraft centered, track up
  - PLAN: entire airport centered, North up
  - Range knob:
    - MAP: scale .25, .5, 1, 2*, 2*, 2* (*declutter)
    - PLAN: no range change; declutter only
- Symbology:
  - Standard: tip of chevron is aircraft position
  - Surface: ⅓ back from tip is aircraft position

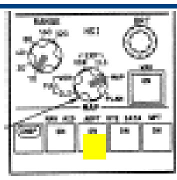
MAP

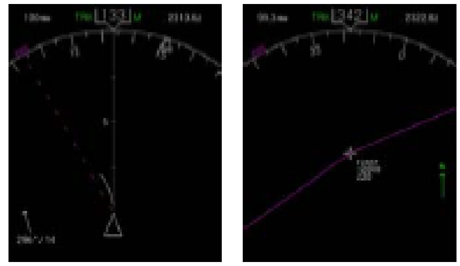


PLAN

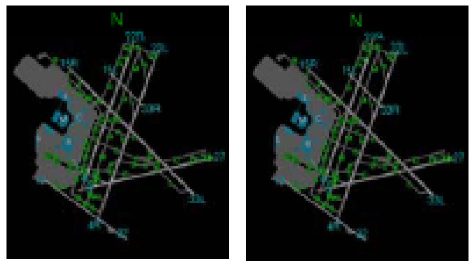
24

Navigation Display while Airborne





- **ARPT Button not depressed:**
  - Standard MAP & PLAN displays
    - never display taxi routes
  - Range functions standard:
    - Airborne: 10, 20, 40, 80, 160, 320
- **ARPT Button depressed:**
  - MAP: entire airport centered, North up
    - EXCEPT: < 1000'AGL (reverts to MAP, aircraft centered, track up)
  - PLAN: entire airport centered, North up
  - Range knob:
    - MAP: scale .25, .5, 1, 2*, 2*, 2* (* declutter)
    - PLAN: no range change, declutter only
- *NOTE: Taxiway D has gap in ND display by Rwy 27 in higher range scales*



MAP PLAN

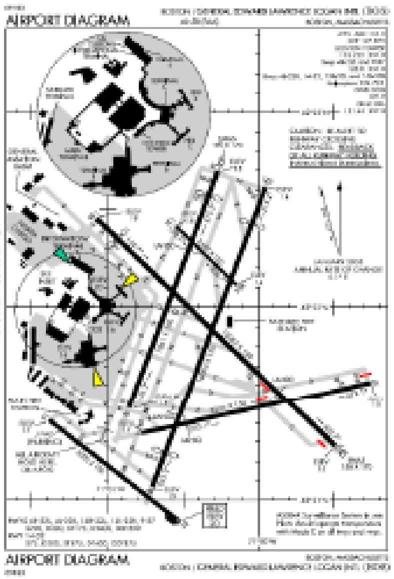
25

Part Task Training

- **Data Comm messages**
  - Data Comm chime
  - ATC Home Page and ATC Log page
  - Accessing Data Comm message
  - Types of Data Comm message
    - Expected Taxi, Proposed Taxi, Cleared Taxi
    - Altimeter, ATIS
    - changes to route or altitude restrictions (pre-loaded only)
  - Responding to Data Comm Uplink message
    - WILCO for directive, ROGER for informational
  - Requesting via Data Comm Downlink message
    - Start, Pushback, Taxi route
- **Displaying taxi route on ND**
  - Page 1 of Data Comm message, press LOAD (L6)
  - (1) ARPT button and (2) either MAP or PLAN
  - Range button acts as declutter

26

Training: Airfield



- Depart Gate E8A ; various Arrival gates
- Parallel taxiways A and B are bi-directional
  - intended to align with current BOS procedures
- Only RWY 27 and RWY 33L are active
  - intended to combine current BOS NW-flow procedures and research at the FAA Technical Center
  - Voice, Data Comm and ND displays will have Hold Short instructions and red bars for Runway 27 and 33L
  - Voice, Data Comm and ND displays will not have Hold Short instructions or red bars for Runway 22R and 22L
    - ignore hold short signs and taxiway paint for RWY 22R / 22L
    - do not switch to tower or request permission to cross RWY 22
  - Will have runway identifier in Data Comm taxi message
    - Cactus517, RWY33L via Z.B.F.H.22L.C. Hold Short RWY27
- ATC Voice clearance always required to begin taxiing or to cross RWY 27 & RWY 33L
  - Crew checks in on Tower frequency using Voice with "Tower, NASA557 Holding Short 27" or "Ready to cross 27"
  - ATC Voice and Data Comm messages will be sent simultaneously
  - Captain immediately begins to taxi, FO updates Data Comm

NOTE: 2 Tower and 2 Approach frequencies

NOTE: "X" is closed taxiway, not "Taxiway X-Ray"

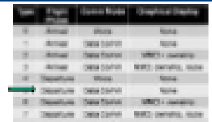
27

Training: Depart, Voice, Paper

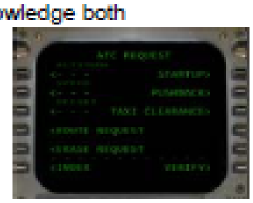
- Start: Gate E8A
  - crew fills out questionnaire for previous scenario on Table PC
  - researcher configures aircraft, loads FMC with SID, etc
  - researcher gives scenario brief (type scenario, clearance, runway, altimeter)
- Simulator to Operate when crew ready (called by researcher)
- Crew actions after in Operate:
  - before start checklist, departure briefing, verify info in FMC, V speeds, etc
  - confirm with ground ready for pushback, request with ATC via voice
  - comm with ground done by talking to researcher (no intercom button push)
- Taxi clearance and operations:
  - call for Taxi clearance; standard readback of Taxi clearance
  - cleared to begin taxiing the aircraft when clearance received (current day ops)
  - taxi as soon as cleared; turns 10 knots, straight 20 knots (if feasible)
  - RWY22R and RWY22L are NOTAMed closed, available for taxi
    - clearance not req to cross these runways; disregard visual out the window
- Use "ACARS message" (Zero Fuel Weight) to recalculate V speeds
- Hold short RWY27 or RWY33L; use voice to request across
- Departure scenarios terminate when in position for takeoff

28

Training: Depart, D/C, Paper



- Start: Gate E8A; sim to Operate when crew ready
- Crew actions after in Operate :
  - before start checklist, departure briefing, FMC info, etc
  - request separate Pushback and Start with ATC via Data Comm
  - ATC will respond with two separate Data Comm; FO acknowledge both
    - Pushback time based on GMT (clock by FO knee)



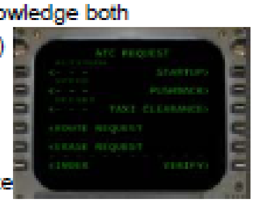
- Taxi operations:
  - ATC sends Expected Taxi message
    - anytime from sim in Operate to FO requesting Taxi
  - FO requests Taxi Clearance via CDU after engine start
  - ATC responds with Data Comm Taxi Clearance of the route
  - FO calls via Voice "Ground, NASA557 ready to taxi"
  - ATC responds "NASA557, taxi via data link route"
  - RWY22R and RWY22L are closed, available for taxi
  - **NOTE**: FO responds only with D/C to Amended Taxi msg

- Use ZFW to recalculate V speeds (PEGASUS or card)
- Hold short RWY27 or RWY33L
  - use voice to request across once on Tower frequency
  - simultaneous Voice and Data Comm response from Tower to cross

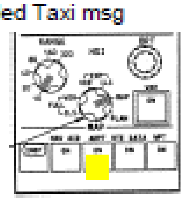
29

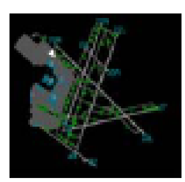
Training: Depart, D/C, MMD

- Start: Gate E8A; sim to Operate when crew ready
- Crew actions after in Operate :
  - before start checklist, departure briefing, FMC info, etc
  - request separate Pushback and Start with ATC via Data Comm
  - ATC will respond with two separate Data Comm; FO acknowledge both
  - pushback grd ops same (talk with researcher, no intercom)



- Taxi operations:
  - ATC sends Expected Taxi message
  - FO requests Taxi Clearance via CDU after engine start
  - ATC responds with Data Comm Taxi Clearance of the route
  - FO calls via Voice "Ground, NASA557 ready to taxi"
  - ATC responds "NASA557, taxi via data link route"
  - RWY22R and RWY22L are closed, available for taxi
  - **NOTE**: FO responds only with D/C to Amended Taxi msg
- Use ZFW to recalculate V speeds
- Hold short RWY27 or RWY33L
- Ownship position on Moving Map Display
  - depress ARPT button and MAP or PLAN



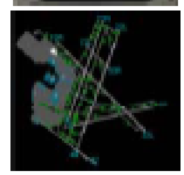


30

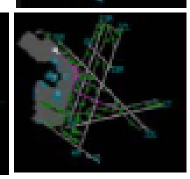
Training: Depart, D/C, MMD + route

- Start: Gate E8A; sim to Operate when crew ready
- Crew actions after in Operate :
  - before start checklist, departure briefing, FMC info, etc
  - request separate Pushback and Start with ATC via Data Comm
  - ATC will respond with two separate Data Comm; FO acknowledge both
  - pushback grd ops same (talk with researcher, no intercom)

- Taxi operations:
  - ATC sends Expected Taxi message
    - PM should load on ND to review prior to ROGER
  - FO requests Taxi via CDU; ATC responds with D/C
    - PM should load on ND to review prior to WILCO
  - FO calls via Voice "Ground, NASA557 ready to taxi"
  - ATC responds "NASA557, taxi via data link route"
  - **NOTE**: FO responds only with D/C to Amended Taxi msg

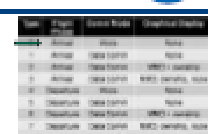


- Use ZFW to recalculate V speeds
- Hold short RWY27 or RWY33L
- Ownship position and route on Moving Map
  - depress ARPT button and MAP or PLAN



31

Training: Arrival, Voice, Paper



- Start: 18,000' in descent
  - ORW at 300KIAS: SFO-BOS, ORW3, ILS33L
    - Cross PVD at 110/250KIAS
  - ARMUM at 270KIAS: DEN-BOS, SCUP4, ILS27
    - Initial segment steep (need speed brake)
  - review pre-loaded messages
  - accomplish approach checklist prior to Sim in Operate
- Simulator to Operate when crew ready (called by researcher)
- Crew actions after in Operate :
  - ATIS, run all checklists, visual lookout for traffic, etc
- Taxi clearance and operations:
  - no party-line voice on Approach freq (initially quite compared to Departure)
  - Tower may request early turn-off if feasible (safety & normal ops take priority)
    - to assist traffic flow; if cannot turn off, researcher will intervene (no problem)
  - "Grnd, NASA557 clear Rwy 27"; ATC gives taxi clearance; FO read back
  - RWY22R and RWY22L are NOTAMed closed, available for taxi
    - clearance not req to cross these runways; disregard visual out the window
- Arrival scenarios terminate during taxi in and prior to reaching Gate

32

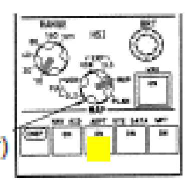
Training: Arrival, D/C, Paper

- Start: 18,000' in descent
  - ORW at 300KIAS: SFO-BOS, ORW3, ILS33L
    - Pre-loaded: Cross PVD at 110/250KIAS
  - ARMUM at 270KIAS: DEN-BOS, SCUP4, ILS27
    - Pre-loaded: Cross SCUPP at 110/230KIAS (need speed brake)
  - accomplish checklist & review FMC prior to Sim in Operate
- Simulator to Operate when crew ready (called by researcher)
- Crew actions after in Operate :
  - ATIS, run all checklists, visual lookout for traffic, etc
  - respond to all Data Comm messages when workload permits
    - Expected Taxi routes, ATIS, Altimeter settings, frequency changes
- Taxi clearance and operations:
  - Expected Taxi message or Tower may request early turn-off if feasible
    - if cannot turn off, roll-out to the end & researcher will intervene (no problem)
  - Data Comm Taxi message received during roll-out
    - use SOP and judgment to prioritize when to WILCO (pg 2, R5)
  - "NASA557 clear 27"; ATC Voice "NASA557, taxi via data link route"; "WILCO"
  - **NOTE**: FO responds only via Data Comm to Amended Taxi msg (pg 2, R5)

33

Training: Arrival, D/C, MMD

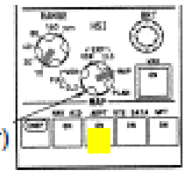
- Start: 18,000' in descent
  - ORW at 300KIAS: SFO-BOS, ORW3, ILS33L
    - Cross PVD at 110/250KIAS
  - ARMUM at 270KIAS: DEN-BOS, SCUP4, ILS27
    - Initial segment steep (need speed brake)
  - review pre-loaded messages
  - accomplish approach checklist prior to Sim in Operate
- Simulator to Operate when crew ready (called by researcher)



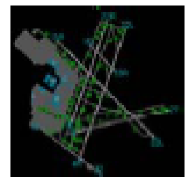
- Crew actions after in Operate :
  - ATIS, run all checklists, visual lookout for traffic, etc
  - respond to all Data Comm messages when workload permits
    - Expected Taxi routes, ATIS, Altimeter settings, etc
  - Moving Map Display with ownship position is available
- Taxi clearance and operations:
  - Expected Taxi message or Tower may request early turn-off if feasible
  - will receive Data Comm Taxi message during roll-out (use SOP to prioritize)
  - "NASA557 clear 27"; ATC Voice "NASA557, taxi via data link route"; "WILCO"
  - RWY22R and RWY22L are NOTAMed closed, available for taxi
- Arrival scenarios terminate during taxi in and prior to reaching Gate

34

Training: Arrival, D/C, MMD + route



- Start: 18,000' in descent
  - ORW at 300KIAS: SFO-BOS, ORW3, ILS33L
    - Cross PVD at 110/250KIAS
  - ARMUM at 270KIAS: DEN-BOS, SCUP4, ILS27
    - Initial segment steep (need speed brake)
  - review pre-loaded messages
  - accomplish approach checklist prior to Sim in Operate
- Simulator to Operate when crew ready (called by researcher)
- Crew actions after in Operate :
  - ATIS, run all checklists, visual lookout for traffic, etc
  - respond to all Data Comm messages when workload permits
    - Expected Taxi routes, ATIS, Altimeter settings, etc
  - Moving Map Display with ownship position and route is available



- Taxi clearance and operations:
  - Expected Taxi message or Tower may request early turn-off if feasible
  - will receive Data Comm Taxi message during roll-out (use SOP to prioritize)
  - "NASA557 clear 27"; ATC Voice "NASA557, taxi via data link route"; "WILCO"
  - RWY22R and RWY22L are NOTAMed closed, available for taxi
  - **NOTE**: FO responds only with D/C to Amended Taxi msg

35

Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

36

Questionnaires

1. Biographical questionnaire (paper)
   – Update data base; separates personal info from data collection
2. NEO-FFI (paper)
   – Personality trait, sent prior to arriving (finish tonight if not complete)
3. Post-scenario questionnaire (computer)
   – Workload, SA, Usability
   – Automation Use
4. Post-experiment (computer and paper)
   – Workload Comparison, SA Comparison,
   – Crew Coordination
   – Acceptability
   – Trust, Crew Interaction
   – Problems, limitations (written response)

– CAUTION: keep hands and Tablet PC clear of yoke when sim is RESET
– No inter-crew chat during post-scenario questionnaire
– Post-experiment questionnaire and debrief session for free-form comments

37

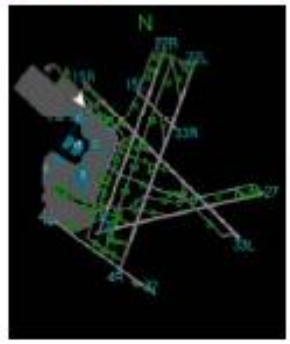
Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

38

Integration Flight Deck (IFD)

- IFD:
  - B757-200 "Class D" Sim
    - PEGASUS FMC
      - calculates V_{ref} but not V_1, V_R, V_2
    - Datalink via CDU
    - Moving Map (when appropriate)
    - Oculometers & overhead cameras
  - NO food, drinks, gum, cell phone



39

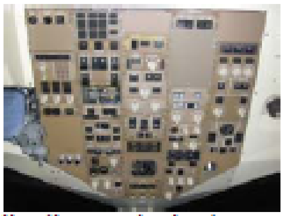
Integration Flight Deck (IFD)

- IFD Differences:
  - Oculometer installation
    - watch head getting into seat
  - Overhead panel & HUD
  - Fixed side windows
  - Simulator controls
  - Event markers: dash & yoke
  - FMC in HOLD or OPERATE
  - 3rd CDU for researcher
  - FO radio control (outboard)

40

Integration Flight Deck (IFD)

- **IFD “Squawks”:**
  – Auto brake light always ON
  – Tiller: no feedback, won’t override rudder
  – APU does not operate properly:
    - switch does not stay in GRD; incorrect PSI



  – Engine start sequence not correct (too fast, indications missing)
  – Throttle friction is too high; Auto-throttle “hunts”
  – Yoke does not have full down movement
  – EICAS Engine Button has to be pressed twice to view indications
  – Altimeters: changing window does not change pointer
  – Upper/right ND speed correct; airspeed indicators 3 knots fast
  – Approach button difficult to depress
  – True/Magnetic switch inop
  – Parking brake light difficult to depress

41

Integration Flight Deck (IFD)

- **IFD “Simizms”:**
  – Avionics available in operate (VNAV, ATIS, etc)
    - Left control for ATC (C knob), right for ATIS (R knob)
    - R knob volume for researcher acting as ATC
    - Navaid frequency station ID dots/dashes not available

  – VNAV doesn’t engage if TMC in wrong phase
    - set cruise altitude & cost index; arrival scenarios select CRZ or Descend Now
  – Nav display during approach occasionally does not have dashed white line for extended runway centerline; sometimes reverts to wrong runway
    - check correct runways are loaded in Route 1 and 2 prior to start Arrival scenario
  – Sometimes lights visible at unrealistic distances; estimation can be difficult
  – Departures start with engines off; indications correct when in OPERATE

42

IFD Documentation

- Checklists, performance
- Zero Fuel Weight

BEFORE START

PARKING BRAKE .... SET, PRESSURE NORMAL
V SPEEDS .... ___, ___, ___ SET
FMS .... PROGRAMMED
FUEL CONTROL SWITCHES .... CUT OFF
EICAS .... CHECKED
ALTIMETERS .... ___, SET
TRIM .... ___, ___, ___, SET

BEFORE TAKEOFF

DEPARTURE BRIEFING .... REVIEWED, RWY ___
FLAPS .... ___ PLAN, ___ INDICATED, DETENT
T.O. DATA .... SET
EPR .... REDUCED/MAX SET
ENGINE ANTI-ICE .... ON/OFF
AUTOBRAKES .... RTO
FLIGHT CONTROLS .... CHECKED
MANIFEST CHANGES .... CHECKED AND SET
MCP .... ___, ___, ___ SET

CABIN NOTIFICATION .... COMPLETED
TRANSPONDER .... ON
EICAS .... RECALL/CANCEL

AFTER TAKEOFF

GEAR LEVER .... OFF
FLAPS/SLATS .... UP

APPROACH DESCENT

ALTIMETERS .... SET
PRESSURIZATION .... SET
EICAS .... CHECKED
AUTOBRAKES .... SET
LANDING DATA .... BUGS SET
APPROACH NAV INSTRUMENTS .... SET
APPROACH BRIEFING .... REVIEWED

LANDING

SPEEDBRAKE .... ARMED
GEAR .... VERIFY .... DOWN, 3 GREEN
FLAPS .... (Position)

43

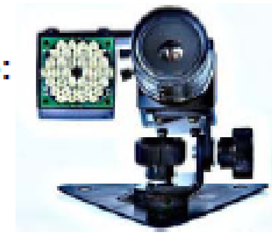
Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

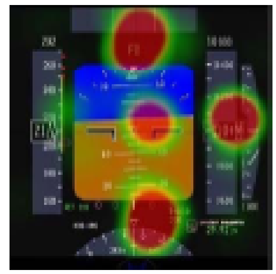
44

Oculometers

- 10 camera system (5 per pilot)
- The oculometer provides in real-time:
  - Gaze vectors for each crew, for each eye
  - Head and eye position (each eye) for each crew
  - Eyelid closure distance for each eye for each crew
  - Pupil size for each eye for each crew



- Derived data includes the following:
  - Blink rates
  - Area of Interest
  - Fatigue
  - Workload
  - Head Up / Head Down Time



45

Oculometer calibration

- Be consistent
  - either always wear glasses (including calibration), or never wear them
  - sit in same location every time
  - prefer glasses not be worn if okay (may use for short periods of time)
- Find your proper eye point
  - align white ball in front of red ball
  - may deviate slightly, but same deviation for all runs
- Calibration:
  - 1) create profile by gazing at various points
    - Lower EICAS, Center windshield post, RMI, Clock, L/R windshield post
  - 2) view cameras while turning head, keep camera in sight
  - 3) gaze at point (center of circle grid) for 10 seconds each
    - PFD, Nav Display, EICAS, CDU, etc

- During the scenarios:
  - attempt to keep hands off glare shield (blocks LED)
  - avoid touching cameras, notify researchers if accidentally bumped

46

Outline

- Introduction
- Data Comm Experiment
- Messages and Displays
- Questionnaires
- IFD Training
- Oculometers
- Training Runs

47

Experiment Runs

- 3 practice training runs
  - departure, arrival, departure
    - simulating complex environment requires scripting, and assumes the crew:
      - is paying attention and responding within a reasonable time
      - taxi approximately 10 knots in turns and 20 knots on straight-aways
- 1 “Graduation Exercise” training run
  - Arrival scenario, all data being collected
  - Post scenario questionnaire to be filled out
- 17 Experiment runs
  - 8 arrival and 9 departure scenarios
  - Post scenario questionnaire to be filled out each time
  - One post-experiment questionnaire to be filled out at the end

48

Summary

- High-density, high-work load, comparing typical today Voice ops to extreme case of Data Comm ops
- No aircraft emergencies or abnormal operations, however expect operational errors
- Have a crew plan for responding to Data Comm messages on CDU and displaying routes on ND
  - make recommendations and comments during final debrief
- Hand-flying and quick repetitions are tiring
  - stay vigilant and monitor your fatigue, keep researchers informed
- Treat simulation as realistically as possible
  - taxi when cleared; use 10 knots in turns and 20 knots when straight
  - comply with ATC requests (turn-offs, change speeds, etc)
  - use SOP and best crew coordination

Thanks for coming to Langley and participating!

49

Welcome to Data Comm Debrief

- High-density, high-work load, comparing typical today Voice ops to extreme case of Data Comm ops
- Not a checkride, want data and opinion on:
  - when to use Data Comm (messages from controllers in 2017)
  - how to use Data Comm (avionics in the cockpit in 2017)

Thanks for coming to Langley and participating!

50

Appendix J: Scenario Briefings

This Appendix provides the scenario briefings given to subject pilots prior to starting the run. After acknowledging the briefing, the flight crew finished configuring the simulator, accomplished the Descent Checklist, then notified the researcher that they were ready to begin the run. Section J.1 contains the briefings for the NORWICH3 arrival to Runway 33L, Section J.2 the SCUPP4 arrival to Runway 27, Section J.3 the departures to Runway 27, and Section J.4 the departures to Runway 33L.

J.1 NORWICH3 (Arrival to Runway 33L)

NW3A (101, 102): This is a Voice scenario, with paper airport diagram only. Your Callsign is NASA 557. You are on a flight from KSFO to KBOS, and this scenario starts overhead NORWICH, established on the NORWICH THREE Arrival. You have previously been cleared for the NORWICH THREE Arrival, and down to 11,000 ft. You have previously been told to cross Providence at 11,000 feet and 250 KIAS. The FMS has been programmed for the NORWICH THREE Arrival, and the ILS Runway 33L Approach. You are in a descent, passing 18,000 ft at 300 KIAS, with Speedbrakes retracted. Altimeter setting is 30.00. You are established on Boston Approach Frequency 120.6. The Descent Checklist and Approach Brief have not been accomplished yet. You have been assigned Gate E2, which is at the Northeastern edge of Terminal E. The Autopilot, TCAS, and ACARS are inoperative. Moving Map Displays are not available. Data Comm is not in use.

NW3B/C (321, 322, 581): This is a Data Comm scenario, with Moving Map Displays, and no routes. Your Callsign is NASA 557. You are on a flight from KSFO to KBOS, and this scenario starts overhead NORWICH, established on the NORWICH THREE Arrival. You have previously been cleared for the NORWICH THREE Arrival, and down to 11,000 ft. The FMS has been programmed for the NORWICH THREE Arrival, and the ILS Runway 33L Approach. You are in a descent, passing 18,000 ft at 300 KIAS, with Speedbrakes retracted. Altimeter setting is 30.02. You are established on Boston Approach Frequency 120.6. The Descent Checklist and Approach Brief have not been accomplished yet. You have been assigned Gate E2, which is at the Northeastern edge of Terminal E. The Autopilot, TCAS, and ACARS are inoperative. Moving Map Displays are available, depicting Ownship only (no route). Data Comm is in use. You have previously received Data Comm messages from Boston Center (KZBW) and Boston Approach (KBOS) which may be reviewed prior to starting the run.

J.2 SCUPP4 (Arrival to Runway 27)

SC4A (211, 212): This is a Data Comm scenario, with paper airport diagram only. Your Callsign is NASA 557. You are on a flight from KDEN to KBOS, and this scenario starts overhead ARMUN, established on the SCUPP4 Arrival. You have previously been cleared for the SCUPP4 Arrival, and down to 11,000 ft. The FMS has been programmed for the SCUPP4 Arrival, and the ILS Runway 27 Approach. You are in a descent, passing 18,000 ft at 270 KIAS, with Speedbrakes retracted. Altimeter setting is 29.98. You are on Boston Approach Frequency 120.6. The Descent Checklist and Approach Brief have not been accomplished yet. You have been assigned Gate B20, which is at the Southern edge of Terminal B. The Autopilot, TCAS, and ACARS are inoperative. Moving Map Displays are not available. Data Comm is in use. You have previously received Data Comm messages from Boston Center (KZBW) and Boston Approach (KBOS) which may be reviewed prior to starting the run.

SC4B/C (431, 432, 381): This is a Data Comm scenario, with Moving Map Displays, and no routes. Your Callsign is NASA 557. You are on a flight from KDEN to KBOS, and this scenario starts overhead ARMUN, established on the SCUPP4 Arrival. You have previously been cleared for the SCUPP4

Arrival, and down to 11,000 ft. The FMS has been programmed for the SCUPP4 Arrival, and the ILS Runway 27 Approach. You are in a descent, passing 18,000 ft at 270 KIAS, with speed brakes retracted. Altimeter setting is 30.04. You are established on Boston Approach Frequency 120.6. The Descent Checklist and Approach Brief have not been accomplished yet. You have been assigned Gate B20, which is at the Southern edge of Terminal B. The Autopilot, TCAS, and ACARS are inoperative. Moving Map Displays are available, with route depictions. Data Comm is in use. You have previously received Data Comm messages from Boston Center (KZBW) and Boston Approach (KBOS) which may be reviewed prior to starting the run.

J.3 Runway 27 (Departure to Runway 27)

RWY27A/C (141, 142, 181): This is a Voice scenario, with paper airport diagram only. Your Callsign is NASA 557. This scenario starts parked at Boston Logan Terminal E, Gate E-8A, which is at the North West corner of the terminal. You are on Auxiliary Power Unit (APU) power, with the engines shut down. You have previously received your clearance to KDEN, as per your Dispatch paperwork. The FMS has been programmed for a LOGAN FOUR Departure. You are on Boston Ground Frequency 121.9, and have not asked for pushback yet. Moving Map Displays are not available. Data Comm is not in use. Your planned Gross Weight is 200,000 pounds. You will receive your final fuel, weight, and takeoff power settings during taxi out.

RWY27B/T (361, 362, 571): This a Data Comm scenario, with Moving Map Displays, and no routes. Your Callsign is NASA 557. This scenario starts parked at Boston Logan Terminal E, Gate E-8A, which is at the North West corner of the terminal. You are on APU power, with the engines shut down. You have previously received your clearance to KDEN, as per your Dispatch paperwork. The FMS has been programmed for a LOGAN FOUR Departure. You are on Boston Ground Frequency 121.9, and have not asked for pushback yet. Moving Map Displays are available, without routes. Data Comm is in use for D-TAXI only. Your planned gross weight is 200,000 pounds. You will receive your final fuel, weight, and takeoff power settings during taxi out.

J.4 Runway 33L (Departure to Runway 33L)

RWY33LA/C (251, 252, 281): This is a Data Comm scenario, with paper airport diagram only. Your Callsign is NASA 557. This scenario starts parked at Boston Logan Terminal E, Gate E-8A, which is at the North West corner of the terminal. You are on APU power, with the engines shut down. You have previously received your clearance to KORD, as per your Dispatch paperwork. The FMS has been programmed for a LOGAN FOUR Departure. You are on Boston Ground Frequency 121.9, and have not asked for pushback yet. Moving Map Displays are not available. Data Comm is in use for D-TAXI only. Your planned Gross Weight is 200,000 pounds. You will receive your final fuel, weight, and takeoff power settings during taxi out.

RWY33LB (471, 472): This is a Data Comm scenario, with Moving Map Displays and displayed routes. Your Callsign is NASA 557. This scenario starts parked at Boston Logan Terminal E, Gate E-8A, which is at the North West corner of the terminal. You are on APU power, with the engines shut down. You have previously received your clearance to KORD, as per your Dispatch paperwork. The FMS has been programmed for a LOGAN FOUR Departure. You are on Boston Ground Frequency 121.9, and have not asked for pushback yet. Moving Map Displays are available, with routes loadable. Data Comm is in use for D-TAXI only. Your planned Gross Weight is 200,000 pounds. You will receive your final fuel, weight, and takeoff power settings during taxi out.

Appendix K: Response Time, Technical Performance, and Raw Data

Section K.1 contains all flight crew response time to Data Comm uplink messages, Section K.2 the technical performance data, and Section K.3 taxi speed data and raw data. All Data Comm response times, including responses longer than two minutes or no response at all, are included in analysis in this Appendix.

K.1 Message Response Time by Altitude

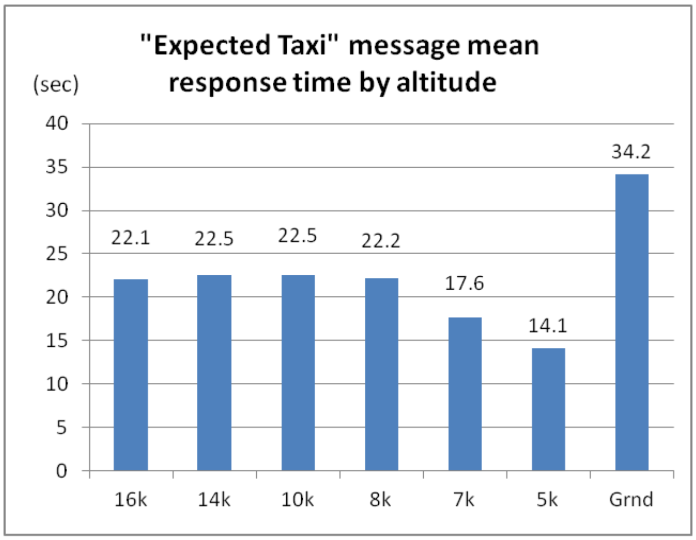


Figure 46. Mean response time to "Expected Taxi" message

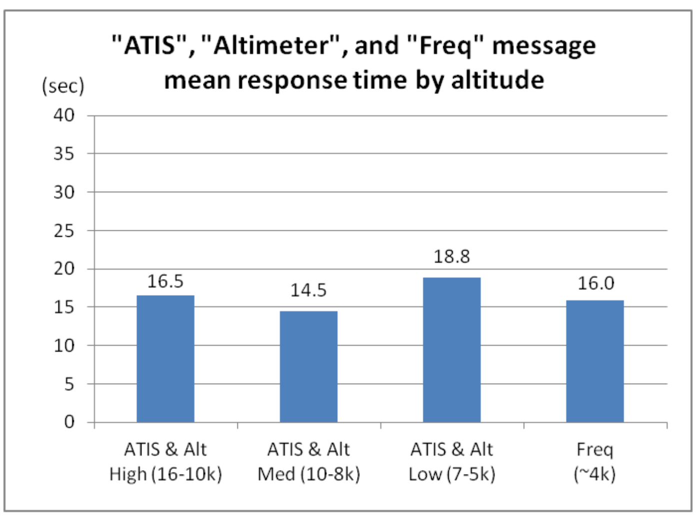


Figure 47. Mean response time to other Data Comm messages

K.2 Technical Performance

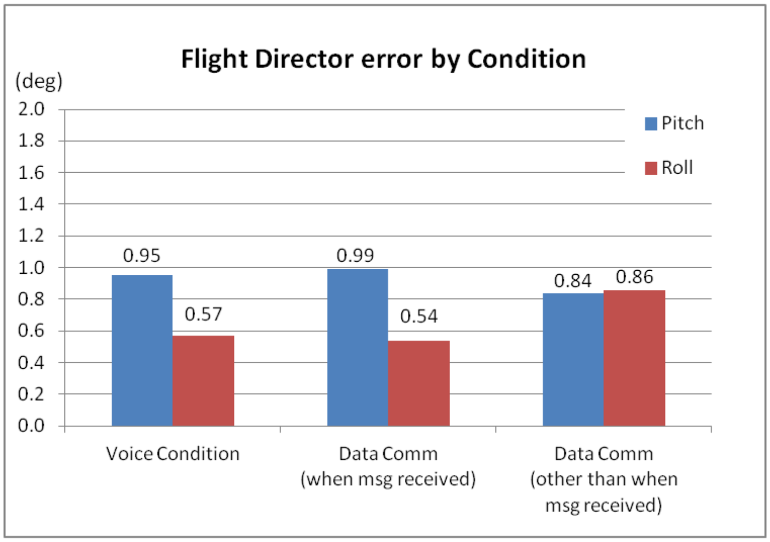


Figure 48. Flight director error by condition

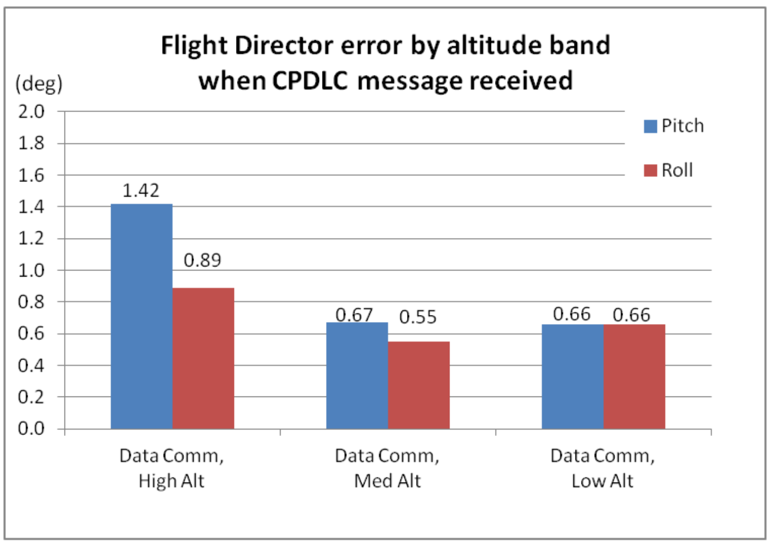


Figure 49. Flight director error by altitude

K.3 Raw Data by Flight Crew

K.3.1 Crew #1

Case	FFT	PHi	RHi	PMed	RMed	PLo	RLo	Speed
101	149.366	14.1715	1.08809	1.07304	0.48745	2.38934	2.12056	11.686
102	105.56	1.08889	0.510826	0.394965	0.465789	1.12355	1.00067	13.2642
141	215.42							14.8441
142	163.955							15.8511
211	107.046	0.972034	2.14148	1.19787	0.366861	0.628553	1.06391	17.9302
212	161.401	1.27553	3.32545	0.714089	0.639086	0.749183	1.05957	17.5616
251	261.854							12.456
252	215.47							12.1418
321	170.269	1.2246	0.546343	0.562557	0.751591	1.16314	0.80011	12.1191
322	143.234	0.779051	0.699372	0.634905	0.724379	0.735014	1.02785	12.625
361	251.308							13.5332
362	219.186							13.2061
431	77.4489	0.96633	1.18762	0.726401	0.462957	0.890507	1.1803	26.4843
432	94.6036	1.15734	1.84873	0.598803	0.441922	1.07572	0.4209	13.9122
471	317.448							12.0131
472	278.071							13.6352

Case	Msg	# Early Views	# Total Views	Resp Time	Recv Time	View Time	View Time	...	Note: only time for first 9 views are shown				
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0								
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	3	31.06	242.38	250.18	277.56	322.86					
211	KBOS ALTIMETER 30.02	1	1	19.96	270.02	281.96							
211	EXPECT TAXI TO TERMINAL B VIA E	3	7	21.32	338.9	345.96	349.62	353.56	362.3	418.28	458.58	473.64	
211	KBOS ATIS ECHO CURRENT	1	2	56.18	350.04	366.04	411.32						
211	CONTACT BOS TOWER 132.22	2	4	18.22	541.84	553.58	556.88	563.58	593.72				
211	TAXI TO TERMINAL B VIA K.E-1	1	4	53.52	760.76	784.56	790	810.06	815.14				
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	2		810.74	833.88	836.3						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0								
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	4	13.08	239.82	246.48	250.54	253.76	304.38				
212	KBOS ALTIMETER 30.02	1	3	19.32	270.02	283.28	292.9	299.06					
212	EXPECT TAXI TO TERMINAL B VIA E	2	5	32.66	320.62	329.8	332.24	354.56	598.92	600.02			
212	KBOS ATIS ECHO CURRENT	2	3	23.82	350.04	357.48	359.86	376.22					
212	CONTACT BOS TOWER 132.22	2	4	8.04	527.92	531.2	532.9	537.06	539.22				
212	TAXI TO TERMINAL B VIA K.E-1	1	2	27.32	772.48	781.68	800.94						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	16.34	811.64	818.48	828.8	840.18					
251	CLEARED TO START	1	2	7.96	5.04	7.82	16.04						
251	KBOS ATIS HOTEL CURRENT	2	3	71.06	30.04	36.3	49.48	102.9					
251	PUSHBACK AT 1931Z	2	3	80.22	32.64	107.68	108.76	115.3					
251	KBOS ALTIMETER 29.96	1	2	64.12	60	118.12	125.8						
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	3	4	161.7	60.02	128.1	168.04	213.2	224.26				
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	3	8	86.04	180.02	206.6	226.52	228.84	268.44	278.12	288.12	396.9	408.2
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	5	8.54	467.3	469.44	477.62	528.28	589.08	648.36			
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	5	7	278.38	648.46	657.34	709.16	768.44	829.24	917.8	931.08	949.32	
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	2	70.96	995.28	1054.64	1057.6						
252	KBOS ATIS HOTEL CURRENT	2	3	43.6	30.04	51.02	69.14	75.02					
252	KBOS ALTIMETER 29.96	1	2	28.76	60	77.92	89.74						
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	2	5	48.96	60.02	91.22	102.44	111.46	119.16	161.72			
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	2	8	31.76	180.02	187.56	188.74	215.32	221	252.04	308.78	341.08	401.88
252	PUSHBACK AT 1434Z	2	3	17.56	268.2	279.94	281.8	287.26					

252	CLEARED TO START	1	2	19.62	276.92	292.44	300.54							
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	6	8.56	453.82	459.44	461.16	466.98	469.24	521.96	581.24			
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	8	9	361.62	634.58	638.28	642.04	701.32	762.12	821.4	882.2	941.48	994.22	997.26
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	24.8	981.8	999.64	1002.28	1008.46						
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
321	KBOS ALTIMETER 30.02	2	3	20.16	60.02	71.64	73.66	84.16						
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	14.08	81.74	86.42	100.78							
321	KBOS ATIS CHARLIE CURRENT	3	4	454.98	100.04	103.6	143.34	550.7	558.14					
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	6	40.78	134.94	163.1	179.82	336.84	561.42	562.86	999.4			
321	CONTACT BOS TOWER 128.8	2	2	30.58	934.46	957.64	959.46							
321	TAXI TO TERMINAL E VIA N.B.Z	4	5	109.84	1246.98	1250.48	1252.18	1283.34	1354.4	1358.44				
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	2	5	12.32	1336.2	1340.34	1342.62	1351.86	1361.26	1403.42				
322	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322	KBOS ALTIMETER 30.02	1	2	12.56	60.02	68.32	73.56							
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	3	25.64	60.66	75.52	78.34	91.54						
322	KBOS ATIS CHARLIE CURRENT	1	2	13.54	100.04	102.62	117.32							
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	6	18.32	114.62	119.5	135.2	139.14	525.54	558.32	1178.4			
322	CONTACT BOS TOWER 128.8	1	3	7.96	981.32	984.52	991.64	1171.84						
322	TAXI TO TERMINAL E VIA N.B.Z	2	4	17.34	1288.38	1291.62	1293.38	1307.68	1338.42					
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	24.6	1352.84	1356.64	1378.66	1399.22						
361	KBOS ATIS INDIA CURRENT	1	2	39.84	30.04	64.96	71.88							
361	KBOS ALTIMETER 29.90	1	2	26.82	60	73.78	87.92							
361	EXPECT TAXI TO RW 27 VIA A.C.D	1	5	40	60.02	91.14	101.52	105.86	120.08	131.96				
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	8	35.02	180.02	192.14	195.28	216.72	268.56	283.28	308.4	344.08	403.36	
361	PUSHBACK AT 2158Z	1	2	12.16	232.3	239.5	246.64							
361	CLEARED TO START	1	2	20.74	236.28	249.58	258.3							
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	6	33.68	484.66	486.68	493.38	520.12	523.44	584.24	643.52			
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	1	7	16.68	661.24	667.02	679.76	704.32	774.56	824.4	883.68	944.48		
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	3	6.56	992.64	996.44	1001.16	1003.76						
362	KBOS ATIS INDIA CURRENT	1	2	32	30.04	59.1	65.52							
362	KBOS ALTIMETER 29.90	1	2	20.6	60	69.24	82.5							
362	EXPECT TAXI TO RW 27 VIA A.C.D	1	3	30.66	60.02	84.86	92.54	123.28						
362	PUSHBACK AT 1648Z	1	2	9.56	151.12	157	161.66							
362	CLEARED TO START	1	2	11.76	154.76	163.8	167.6							
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	5	31.42	180.02	204.08	206.98	213.86	243.36	302.64				
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	6	20.56	377.06	379	400.32	422.72	458.96	482	550.58			
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	1	7	8.14	560.6	563.78	569.5	602.08	662.88	722.16	782.96	842.24		
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	3	19.16	885.04	887.84	903.04	907.84						
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	4	5	51.18	365.5	370.36	374.12	385.1	414.36	418.4				
431	KBOS ALTIMETER 30.02	1	2	19.56	410.04	420.94	433.74							
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	3	18.98	434.94	438.76	444.38	458.06						
431	KBOS ATIS GOLF CURRENT	1	3	6.38	490.04	491.5	500.62	504.8						
431	CONTACT BOS TOWER 132.22	2	4	11.34	550.22	553.6	555.22	564.68	625.26					
431	TAXI TO TERMINAL B VIA K.B.A-2	2	3	46.48	804.42	815.54	817.16	852.04						
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	2		846.96	854.3	865.42							
432	CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	0								
432	EXPECT TAXI TO TERMINAL B VIA E	3	5	38.82	354.04	361.46	363.6	385	397.48	399				
432	KBOS ALTIMETER 30.02	2	3	14.4	410.04	415.08	417.18	426.34						
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	6	24.78	420.88	428.6	437.14	450.68	694.26	699.96	759.24			
432	KBOS ATIS GOLF CURRENT	2	4	17.78	490.04	494.78	498.24	513	519.08					
432	CONTACT BOS TOWER 132.22	1	2	143.2	541.68	681.08	689.32							
432	TAXI TO TERMINAL B VIA K.B.A-2	3	5	13.92	777.84	785.08	787.32	790.1	795.72	820.04				

432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	3	15.56	816.74	825.26	827.74	835.34						
471 KBOS ATIS KILO CURRENT	3	4	120.86	30.04	90.14	97.32	148.72	153.5					
471 KBOS ALTIMETER 30.04	2	3	100.02	60	155.88	156.6	162.96						
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	2	5	152.7	60.02	165.1	188.38	202.74	204.76	214.46				
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	2	8	118.8	120.04	218.2	233.82	242.88	449.66	456.04	516.84	575.7	576.12	
471 PUSHBACK AT 2033Z	1	5	15.74	301.36	310.98	318.7	335.72	337.48	396.76				
471 CLEARED TO START	1	2	17.98	307.02	320.76	329.88							
471 TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	3	8	23.94	624.42	628.58	636.92	637.1	653.32	696.2	757	816.28	877.08	
471 AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	6	13.72	882.16	886.3	890.92	899.88	936.36	997.16	1056.4			
471 AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	5	7	81.56	1202.42	1205.6	1212.2	1227.64	1237.32	1281.2	1289	1296.6		
472 KBOS ATIS KILO CURRENT	1	2	7.76	30.04	34.92	41.54							
472 KBOS ALTIMETER 30.04	1	2	221.78	60	278.74	283.2							
472 EXPECT TAXI TO RW 33L VIA A.F.M.C	1	2	233.9	60.02	289.24	295.46							
472 PUSHBACK AT 1544Z	1	2	12.74	63.62	70.02	77.06							
472 CLEARED TO START	1	3	14.86	67.68	79.2	87.22	88.74						
472 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	1	5	12.08	120.04	127.22	133.38	140.66	148.02	208.82				
472 TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	7	19.06	355.98	364.36	369.16	379.06	388.18	448.98	552.52	569.06		
472 AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	3	9	18.32	619.86	627.4	628.34	632.76	643.54	689.14	748.42	809.22	868.5	929.3
472 AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	10.52	933.98	939.12	942.1	949.06						

Case	Avg Response Time
21x	26.21846154
25x	88.38875
32x	57.33571429
36x	25.96
43x	32.49076923
47x	74.77125

Type	Avg Response Time
Info	60.66083333
Freq	36.55666667
PB/St	20.075
Exp	54.73916667
Taxi	31.89666667
Amd	61.2025

Type	Avg FD Error
PBase	3.3735475
RBase	0.945564167
PRecv	0.980306167
RRecv	0.642142833
POth	0.8474825
ROth	1.236297667
Phi	2.704409375
Rhi	1.418488875
Pmed	0.73782875
Rmed	0.542504375
Plo	1.094375875
Rlo	1.0842335

Alt	Ave "Exp Taxi" Response by Altitude
16k	19.86
14k	29.55
10k	22.07
8k	26.99
7k	45.00
5k	21.88
Grnd	68.10

Alt	Ave "Info" Response Time by Altitude
High	15.42
Med	29.82
Low	14.53
Freq	36.56

K.3.2 Crew #2

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
101	141.985	0.578726	0.551689	0.327997	0.348567	0.376757	0.50933	12.4261
102	218.727	0.539244	0.288038	0.335669	0.127762	0.300909	0.27776	15.1485
141	134.572							15.7687
142	142.315							15.374
211	140.794	0.863612	1.39673	0.311835	0.390249	0.436479	0.20907	15.5857
212	149.735	1.02552	0.883058	0.381577	0.321662	0.246487	0.23317	14.0473
251	163.29							13.5348
252	178.729							12.6262
321	189.654	0.530752	0.695531	0.766574	0.747219	0.444164	0.45737	14.1043
322	150.819	0.754526	0.462274	0.478463	0.722757	0.256304	0.18696	14.6112
361	237.762							11.5302
362	173.188							12.8434
431	162.706	0.762431	0.581643	0.531237	0.317286	0.619704	0.24	18.2016
432	152.963	0.541469	0.515883	0.382952	0.472743	0.334418	0.48248	18.3945
471	185.505							13.3514
472	177.455							13.4533

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim...		Note: only time for first 9 views are shown					
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	28.88	373.36	377.42	380.62	406.8						
211	KBOS ALTIMETER 30.02	1	2	12.14	410.04	413.14	426.56							
211	EXPECT TAXI TO TERMINAL B VIA E	1	2	9.72	437.48	440.74	452.4							
211	KBOS ATIS ECHO CURRENT	1	3	8.6	490.04	493.22	502.56	532.96						
211	CONTACT BOS TOWER 132.22	1	4	12.26	629.78	633.72	646.96	653.04	712.32					
211	TAXI TO TERMINAL B VIA K.E-1	2	3	28	900.88	908.98	927.04	932.72						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	1		950.78	953.78								
212	CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	20.12								
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	19.36	366.36	370.26	375.44	390.64						
212	KBOS ALTIMETER 30.02	1	2	11.9	410.04	413.62	425.6							
212	EXPECT TAXI TO TERMINAL B VIA E	1	2	16.66	446.16	450.18	466.64							
212	KBOS ATIS ECHO CURRENT	2	3	8.52	490.04	493.88	494.04	503.12						
212	CONTACT BOS TOWER 132.22	1	3	9.7	611.22	615.76	624.72	632.32						
212	TAXI TO TERMINAL B VIA K.E-1	1	3	24.1	873.18	885.22	902.88	915.04						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	2		914.6	926.06	974.32							
251	KBOS ATIS HOTEL CURRENT	1	2	6.76	30.04	33.1	41.86							
251	KBOS ALTIMETER 29.96	1	2	53.86	60	110.76	117.86							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	2	7	41.68	60.02	66.92	92.02	105.7	81.48	92.02	102.66	152.82		
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	2	7	43.42	180.02	187.4	212.1	228.82	289.22	332.18	392.98	452.26		
251	CLEARED TO START	1	2	8.16	259.62	264.56	272.9							
251	PUSHBACK AT 2156Z	1	2	16.3	262.78	274.42	283.54							
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	5	9.74	505.16	507.18	519.14	572.34	633.14	692.42				
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	5	17.78	747.6	754.08	769.94	812.5	873.3	932.58				
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	3	14.86	1033.14	1041.38	1052.66	1113.46						
252	KBOS ATIS HOTEL CURRENT	1	6	6.66	30.04	34.38	41.66	36.44	37.1	52.3	111.58			
252	KBOS ALTIMETER 29.96	1	2	10.94	60	67.78	75.1							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	2	3	112.52	60.02	77.46	168.68	176.94						
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	3	4	28.32	180.02	465.44	471.82	185.34	213.42					
252	CLEARED TO START	2	3	9.16	229.8	231.86	235.96	243.82						
252	PUSHBACK AT 1827Z	1	2	16.76	232.86	246.18	254.46							
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	10	14	11.74	466.92	475.3	479.42	531.1	591.9	651.18	711.98	771.26	832.06	891.34
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	7	23.5	663.52	667.9	690.7	711.98	771.26	832.06	891.34	952.14		
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	17.5	994.9	1006.4	1011.42	1017.5						
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									

321	KBOS ALTIMETER 30.02	1	1	13.54	340.04	347.24								
321	KBOS ATIS CHARLIE CURRENT	1	2	9.7	420.04	422.86	434.58							
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	3	53.24	434.4	437.88	466.5	492.34						
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	4	25.7	513.76	532.78	544.02	567.1	875.28					
321	CONTACT BOS TOWER 128.8	1	2	13.98	947.26	955.36	966.58							
321	TAXI TO TERMINAL E VIA N.B.Z	1	3	21.86	1271.5	1277.5	1297.94	1305.54						
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	2	32.1	1330.66	1343.32	1367.86							
322	CROSS PVD AT 11000 FT 250 KIAS	1	1		0	254.16								
322	KBOS ALTIMETER 30.02	1	2	11.98	340.04	343.64	356.44							
322	KBOS ATIS CHARLIE CURRENT	1	2	8.02	420.04	423.5	433.96							
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	3	28.4	424.98	436.54	458.28	493.24						
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	2	13.26	499.56	505.8	517.56							
322	CONTACT BOS TOWER 128.8	1	2	12.62	958.3	964.38	975.08							
322	TAXI TO TERMINAL E VIA N.B.Z	1	2	10.66	1274.38	1277.18	1289.72							
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	2	3	10.42	1324.78	1327.58	1332.28	1339.88						
361	KBOS ATIS INDIA CURRENT	4	5	11.64	30.04	34.96	43.2	91.84	34.74	46.24				
361	KBOS ALTIMETER 29.90	1	2	9.86	60	65.2	73.6							
361	EXPECT TAXI TO RW 27 VIA A.C.D	1	1	20.58	60.02	75.76								
361	CLEARED TO START	1	2	12.92	171.06	180	185.36							
361	PUSHBACK AT 1927Z	1	2	17.62	177.58	189.04	199.76							
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	6	39.7	180.02	201.4	211.92	224.08	271.2	332	391.28			
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	2	6	30.38	433.12	447.24	452.08	468.8	511.36	572.16	631.44			
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	2	8	40.32	665.7	675.52	692.24	710.48	712.66	751.52	812.32	871.6	932.4	
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	4	25.3	941.1	955.34	971.92	991.68	1052.48					
362	KBOS ATIS INDIA CURRENT	1	2	9.24	30.04	33.78	44.88							
362	KBOS ALTIMETER 29.90	1	2	9.76	60	65.2	73.76							
362	EXPECT TAXI TO RW 27 VIA A.C.D	2	4	72.44	60.02	126.74	128.48	75.7	157.34					
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	6	21.72	180.02	184.66	189.28	206	233.1	248.56	309.36			
362	CLEARED TO START	2	3	32.52	182.14	208.2	212.7	219.68						
362	PUSHBACK AT 1529Z	1	2	38.92	184.66	221.16	228.8							
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	5	18.62	389.64	391.84	412.72	429.44	488.72	548				
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	3	7	73.82	598.52	606.44	608.8	668.08	677.2	728.88	788.16	848.96		
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	3	16.9	897.62	907.78	908.24	918.88						
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	2	4	19.22	41.2	45.46	53.32	64.64	72.52					
431	KBOS ALTIMETER 30.02	2	4	28.76	60.02	75.28	82.88	93.52	705.48					
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	3	9	29.7	79.9	96.56	102.8	107.12	113.28	707.96	742.56	803.36	862.64	923.44
431	KBOS ATIS GOLF CURRENT	1	3	24.48	100.04	116.98	130	142.16						
431	CONTACT BOS TOWER 132.22	1	2	19.22	641.7	645.44	665.04							
431	TAXI TO TERMINAL B VIA K.B.A-2	2	4	25.38	930.88	941.44	945.76	961.44	982.72					
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	25.48	982.1	985.6	989.24	1011.6	1042					
432	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432	EXPECT TAXI TO TERMINAL B VIA E	3	4	24.36	51.3	67.6	72.74	73.48	80.34					
432	KBOS ALTIMETER 30.02	1	2	36.06	60.02	82.12	101.62							
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	3	25.62	91.5	103.74	106.5	122.9						
432	KBOS ATIS GOLF CURRENT	1	2	30	100.04	126.92	133.54							
432	CONTACT BOS TOWER 132.22	2	4	18.98	650.1	654.76	657.9	674.66	732.42					
432	TAXI TO TERMINAL B VIA K.B.A-2	2	4	18.7	935.02	944.38	950.1	958.9	972.58					
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	15.4	978.8	985.04	990.98	999.94	1033.38					
471	KBOS ATIS KILO CURRENT	2	4	11.98	30.04	33.06	38.62	46.7	78.62					
471	KBOS ALTIMETER 30.04	8	9	170.12	60	186.4	198.7	230.62	259.5	318.78	378.06	438.86	226.26	235.18
471	EXPECT TAXI TO RW 33L VIA A.F.M.C	2	8	36.4	60.02	73.12	78.62	101.42	102.94	139.42	91.02	96.86	101.98	
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	3	7	36.08	120.04	134.22	139.42	146.96	160.7	321.74	378.06	438.86		
471	CLEARED TO START	1	2	8.8	258.96	264.48	271.66							
471	PUSHBACK AT 2056Z	1	2	18.9	261.22	274.46	285.34							
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	5	15.58	625.76	629.56	638.1	645.58	679.02	738.3				
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	7	33.62	932.84	938.74	955.34	970.86	978.46	1039.26	1098.54	1159.34		

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	17.28	1203.76	1206.74	1218.32	1224.7						
472	KBOS ATIS KILO CURRENT	2	5	8.98	30.04	35.14	37.3	43.38	98.1	157.38				
472	PUSHBACK AT 1634Z	2	3	105.76	54.76	156.24	157.38	164.98						
472	KBOS ALTIMETER 30.04	2	3	23.94	60	69.92	82.16	88.98						
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	3	4	46.34	60.02	91.56	98.1	99.1	111.78					
472	CLEARED TO START	1	2	55.16	64.22	113.64	123.94							
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	2	6	19.02	120.04	127.54	133.18	143.7	382.22	397.54	458.34			
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	8	16.9	425.62	433.52	437.34	447.7	458.34	517.62	578.42	637.7	698.5	
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	8	23.26	700.34	708.04	719.5	728.9	757.78	817.06	877.86	937.14	997.94	
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	19.86	1003.62	1011.84	1018.6	1028.34	1057.22					

Case	Avg Response Time
21x	15.82
25x	28.10375
32x	18.96285714
36x	31.39125
43x	24.38285714
47x	41.74875

Alt	Ave "Exp Taxi" Response by Altitude
16k	21.79
14k	27.66
10k	40.82
8k	19.48
7k	24.12
5k	13.19
Grnd	43.19

Type	Avg Response Time
Info	22.39333333
Freq	14.46
PB/St	28.415
Exp	33.8475
Taxi	19.305
Amd	25.4625

Alt	Ave "Info" Response Time by Altitude
High	29.83
Med	10.81
Low	10.29
Freq	14.46

Type	Avg FD Error
PBase	0.409883667
RBase	0.350524
PRecv	0.488802
RRecv	0.4320335
POth	0.561307667
ROth	0.560324417
Phi	0.699535
Rhi	0.67185575
Pmed	0.439538
Rmed	0.431030625
Plo	0.37690275
Rlo	0.324518375

K.3.3 Crew #3

Case	FFT	PHi	RHi	PMed	RMed	PLo	RLo	Speed
101	178.662	1.45889	0.694062	0.643601	0.429524	0.409572	0.65017	16.3119
102	177.627	0.531248	0.275813	0.858553	0.53744	0.329328	0.31175	10.015
141	215.555							9.88062
142	227.122							13.3123
211	142.63	2.08826	1.30847	0.594199	0.773129	0.778382	0.35791	12.4782
212	131.617	3.59908	1.0216	1.65975	0.610791	0.710013	0.31675	12.8962
251	210.468							10.7346
252	201.132							11.5794
321	147.748	0.677671	0.402953	1.03351	0.680368	0.307236	0.22581	13.0883
322	172.678	2.24885	0.741515	0.675771	0.497287	0.466842	0.31299	18.9733
361	246.779							11.8125
362	249.065							11.5213
431	89.4534	1.55464	0.322087	0.855071	0.549523	1.14421	0.3694	13.0864
432	135.48	4.33429	1.132	1.63064	0.721133	1.52884	0.97719	13.8828
471	300.633							11.2455
472	252.824							11.6259

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim...	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	23.32	49.48	59.7	70.04	77.64						
211	KBOS ALTIMETER 30.02	2	3	67.44	60.02	102.96	125.44	132.36						
211	EXPECT TAXI TO TERMINAL B VIA E	1	6	63	81.36	137.78	149.08	172.14	190.12	292.54	310.2			
211	KBOS ATIS ECHO CURRENT	1	2	63.64	100.04	157.62	168.84							
211	CONTACT BOS TOWER 132.22	1	4	17.02	589.46	593.32	611.16	670.44	729.72					
211	TAXI TO TERMINAL B VIA K.E-1	1	3	24.14	848.22	858.58	877.16	909.08						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	28.8	912.92	930.14	945.56	969.88						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	9.86	35.72	40.46	49.94							
212	KBOS ALTIMETER 30.02	1	2	18.72	60.02	70.78	83.38							
212	EXPECT TAXI TO TERMINAL B VIA E	1	3	27.56	62.42	84.74	94.02	643.28						
212	KBOS ATIS ECHO CURRENT	1	2	11.44	100.04	105.2	116.82							
212	CONTACT BOS TOWER 132.22	1	2	10.04	644.94	649.96	659.46							
212	TAXI TO TERMINAL B VIA K.E-1	1	2	15.22	928.18	936.1	948.26							
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	4	15.6	982.62	990.92	995.38	1002.98	1054.66					
251	KBOS ATIS HOTEL CURRENT	1	2	12.02	30.04	37.6	46.86							
251	KBOS ALTIMETER 29.96	1	2	87.34	60	144.4	151.74							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	1	3	112.34	60.02	153.74	177.58	179.1						
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	1	2	31.84	180.02	184.94	215.58							
251	PUSHBACK AT 2152Z	2	3	29.42	300.16	306.08	326.62	334.14						
251	CLEARED TO START	1	2	20.08	321.22	338.08	346.3							
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	6	20.92	554.08	560.06	578.86	600.14	659.42	720.22	779.5			
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	5	18.78	780.86	785.34	803.82	840.3	899.58	960.38				
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	20.44	1082.06	1085.7	1091.82	1107.82	1139.74					
252	KBOS ATIS HOTEL CURRENT	1	2	7.92	30.04	34.42	41.96							
252	KBOS ALTIMETER 29.96	1	2	7.7	60	65.18	72.36							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	5	6	19.74	60.02	74.32	79.96	95.16	154.44	73.82	84.52			
252	PUSHBACK AT 1644Z	1	2	18.66	98.36	109.58	121							
252	CLEARED TO START	1	2	21.96	106.54	126.08	133.16							
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	6	7	10.68	180.02	189.4	190.92	215.24	274.52	335.32	182.98	195.48		
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	7	12	7.88	391.9	396.1	400.68	455.4	514.68	575.48	634.76	394.12	403.72	455.4
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	8	14	19	629.4	644.26	648.44	694.04	754.84	814.12	874.92	934.2	637.62	653
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	4	9.88	975.02	980.46	988.92	995	1054.28					
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									

321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	5	17.14	487.48	491.62	498.5	509.92	526.06	529.68				
321	KBOS ALTIMETER 30.02	1	2	18.02	500.04	512.58	523.6							
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	9	11.94	530.04	535.28	546.4	551.04	590.48	647.56	649.76	709.04	769.84	829.12
321	KBOS ATIS CHARLIE CURRENT	1	2	9.84	630.04	634.56	643.68							
321	CONTACT BOS TOWER 128.8	1	2	36.78	980.52	1010.6	1022.16							
321	TAXI TO TERMINAL E VIA N.B.Z	2	4	10.02	1304.54	1307.92	1309.44	1318.56	1370.24					
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	16.02	1390.1	1394.64	1411.28	1429.52						
322	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322	KBOS ALTIMETER 30.02	1	2	9.96	500.04	503.54	514.18							
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	3	10.62	536.74	540.16	546.1	552.18						
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	2	11.32	613.54	618	629.7							
322	KBOS ATIS CHARLIE CURRENT	1	2	6.92	630.04	633.5	641.86							
322	CONTACT BOS TOWER 128.8	1	4	51.24	978.2	982.52	991.46	1026.42	1034.02					
322	TAXI TO TERMINAL E VIA N.B.Z	1	3	7.22	1304.88	1307.26	1316.74	1325.86						
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	5	6	15.86	1372.12	1377.34	1385.14	1388.18	1377.48	1385.14	1392.74			
361	KBOS ATIS INDIA CURRENT	1	2	7.04	30.04	32.56	42.3							
361	PUSHBACK AT 2028Z	1	2	10.54	57.1	62.68	72.7							
361	KBOS ALTIMETER 29.90	1	2	19.06	60	75.6	84.86							
361	EXPECT TAXI TO RW 27 VIA A.C.D	1	2	32.94	60.02	87.42	97.02							
361	CLEARED TO START	1	2	13.88	111.6	116.78	130.46							
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	2	11.24	180.02	184.74	195.82							
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	6	10.64	328.24	331.2	343.26	353.9	413.18	473.98	533.26			
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	1	7	20.54	573.82	579.3	598.62	653.34	714.14	773.42	834.22	893.5		
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	3	61.52	882.6	926.94	932.7	949.74						
362	KBOS ATIS INDIA CURRENT	1	2	9.2	30.04	35.12	44.58							
362	KBOS ALTIMETER 29.90	1	2	11.82	60	67.96	76.5							
362	EXPECT TAXI TO RW 27 VIA A.C.D	1	2	23.22	60.02	78.4	88.66							
362	PUSHBACK AT 1527Z	1	2	18.02	101.14	114.38	123.62							
362	CLEARED TO START	1	2	19.64	109.44	126.24	134.26							
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	4	7.12	180.02	183.04	192.02	195.06	255.86					
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	6	11.84	352.08	355.5	368.34	375.94	435.22	496.02	555.3			
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	14	14.96	611.78	663.7	675.38	736.18	795.46	856.26	915.54	976.34	616.24	631.3
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	4	13.32	948.58	955.44	965.7	976.34	1035.62					
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	1	2	8.04	226.42	229.14	239.12							
431	KBOS ALTIMETER 30.02	1	3	10.34	270.02	275.22	284.72	289.28						
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	1	3	16.2	307.64	311.96	328.8	350.08						
431	KBOS ATIS GOLF CURRENT	1	4	9.6	350.04	355.78	363.76	409.36	470.16					
431	CONTACT BOS TOWER 132.22	2	4	16.02	615.66	620.64	624.86	635.84	649.52					
431	TAXI TO TERMINAL B VIA K.B.A-2	1	4	27.72	897.16	907.28	929.2	930.12	950.48					
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	1	4	13.82	965.54	970.54	983.92	992.34	1009.76					
432	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432	EXPECT TAXI TO TERMINAL B VIA E	1	4	9.04	238.24	242.54	252.16	256.64	281.04					
432	KBOS ALTIMETER 30.02	1	2	48.76	270.02	315.16	323.6							
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	13	15.3	321.54	327.9	333.66	341.84	368.54	401.12	461.92	521.2	582	673.68
432	KBOS ATIS GOLF CURRENT	1	2	9.92	350.04	356.16	364.64							
432	CONTACT BOS TOWER 132.22	1	4	35.46	624.2	629.12	639.76	641.28	664.08					
432	TAXI TO TERMINAL B VIA K.B.A-2	1	4	10.34	910.34	914.88	925.52	926.66	942.24					
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	5	11.6	969.84	975.28	978.8	986.32	1001.52	1062.32				
471	KBOS ATIS KILO CURRENT	1	2	10.3	30.04	36.46	45.92							
471	KBOS ALTIMETER 30.04	1	2	9.34	60	63.4	74.8							
471	EXPECT TAXI TO RW 33L VIA A.F.M.C	1	3	23.5	60.02	77	88.48	91.52						
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	4	5	13.3	120.04	471.12	511.04	515.16	125.44	138.64				
471	PUSHBACK AT 1405Z	1	2	15.22	201.84	212.9	222.24							
471	CLEARED TO START	1	2	17.72	209.9	225.14	232.88							
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	13	11.58	503.46	552.08	557.6	571.84	631.12	506.48	511.04	518.64	525.98	571.84
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	3	9	34.38	851.68	869.76	871.28	879.94	891.04	932.08	991.36	1052.16	1111.44	1172.24

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	5	16.76	1174.54	1178.16	1185.66	1196.56	1231.52	1292.32				
472	KBOS ATIS KILO CURRENT	1	2	6.92	30.04	33.94	40.9							
472	PUSHBACK AT 1829Z	1	2	19.2	58.18	73.18	81.94							
472	KBOS ALTIMETER 30.04	1	2	27.7	60	85.5	92.58							
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	3	4	40.6	60.02	111.4	132.1	94.96	104.74					
472	CLEARED TO START	2	5	80.02	65.56	101.86	109.5	116.9	132.1	150.34				
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	6	7	43.98	120.04	167.16	191.38	252.18	311.46	372.26	153.54	168.58		
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	7	13	7.82	379.24	388.98	431.54	492.34	551.62	612.42	671.7	381.3	392.02	431.54
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	12	18	12.02	722.9	734.52	735.54	740.1	791.78	851.06	911.86	971.14	1031.94	1091.22
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	5	9.74	1009.6	1013.58	1024.34	1026.04	1031.94	1091.22				

Case	Avg Response Time
21x	28.27142857
25x	29.7875
32x	16.63571429
36x	19.78375
43x	17.29714286
47x	25.00625

Type	Avg Response Time
Info	20.87333333
Freq	27.76
PB/St	23.69666667
Exp	24.74333333
Taxi	13.77833333
Amd	19.61333333

Type	Avg FD Error
PBase	0.705198667
RBase	0.483125833
PRecv	1.30892
RRecv	0.645829667
POth	1.50281125
ROth	0.620492833
Phi	2.061616125
Rhi	0.7373125
Pmed	0.993886875
Rmed	0.599899375
Plo	0.709302875
Rlo	0.440244

Alt	Ave "Exp Taxi" Response by Altitude
16k	16.59
14k	45.28
10k	8.54
8k	15.75
7k	13.88
5k	11.63
Grnd	30.88

Alt	Ave "Info" Response Time by Altitude
High	40.31
Med	19.66
Low	11.19
Freq	27.76

K.3.4 Crew #4

Crew 4 Summary

Case	FFT	PHi	RHi	PMed	RMed	PLo	RLo	Speed
101	220.17	1.49307	0.466007	0.665529	0.75027	0.326348	1.23283	14.5663
102	101.104	1.05806	0.692027	0.349524	0.506494	0.644793	0.51824	17.8502
141	213.219							14.4462
142	140.835							15.4186
211	175.732	3.24115	0.530347	2.08094	1.27802	0.693234	0.55745	19.1818
212	129.957	2.02686	0.637714	1.10851	2.16454	0.607262	0.80919	17.5125
251	222.713							12.4588
252	229.509							13.7653
321	185.811	0.656137	1.00423	2.32885	0.857205	2.3648	0.80272	16.8009
322	170.849	1.72348	0.44899	1.8322	0.547134	0.412749	0.89361	13.6892
361	239.025							14.6076
362	197.385							13.6069
431	303.348	1.25166	2.43489	1.00308	1.08115	2.30739	0.63647	6.32342
432	150.962	2.57647	1.62073	1.15452	1.2183	1.79945	0.78095	20.7908
471	235.673							9.66315
472	248.151							13.4003

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim…	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	1	2		0	340.64	349.66							
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	6	8	21.16	337.44	339.84	358.78	367.9	423.14	427.18	354.56	362.58	367.9	
211	KBOS ALTIMETER 30.02	3	4	9.04	410.04	414.26	419.58	413.16	424.14					
211	EXPECT TAXI TO TERMINAL B VIA E	4	6	9.12	425.3	428.68	434.78	487.98	427.44	439.34	646.78			
211	KBOS ATIS ECHO CURRENT	1	2	9.72	490.04	495.14	504.7							
211	CONTACT BOS TOWER 132.22	1	2	6.46	605.9	607.98	617.18							
211	TAXI TO TERMINAL B VIA K.E-1	1	2	17.82	889.18	901.82	910.54							
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	10.08	930.94	933.88	945.5	968.3						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	15	17	9.9	392.32	399.4	403.4	416	462.68	496.12	523.48	582.76	642.04	702.84
212	KBOS ALTIMETER 30.02	1	2	9.72	410.04	412.84	424.68							
212	KBOS ATIS ECHO CURRENT	2	2	8.76	490.04	493.54	493.44							
212	EXPECT TAXI TO TERMINAL B VIA E	1	2	7.16	540.18	542.94	552.36							
212	CONTACT BOS TOWER 132.22	1	2	9.22	679.94	682.66	693.72							
212	TAXI TO TERMINAL B VIA K.E-1	1	3	14.48	965.42	971.02	984.04	1002.28						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	2	14.68	1002.24	1006.14	1020.52							
251	CLEARED TO START	2	3	33.66	10.66	16.64	42.24	46.74						
251	PUSHBACK AT 1917Z	2	3	37.22	14.36	20.44	49.16	56.18						
251	KBOS ATIS HOTEL CURRENT	2	2	31.92	30.04	32.5	58.16							
251	KBOS ALTIMETER 29.96	1	1	12.9	60	65.3								
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	5	7	37	60.02	89.54	97.22	112.42	171.7	75.94	101.78	112.42		
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	3	5	26.32	180.02	227.36	232.5	182.62	210.32	236.26				
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	7	9	12.42	245.86	252.94	258.34	280.46	291.78	351.06	411.86	249.22	260.72	291.78
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	7	8	149.74	430.46	442.72	471.14	531.94	580.58	591.22	652.02	577.48	585.14	
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	4	5	13.04	773.86	776.62	787.3	831.38	784.2	791.86				
252	KBOS ATIS HOTEL CURRENT	2	3	10.38	30.04	36.5	34.22	45.3						
252	KBOS ALTIMETER 29.96	1	2	8.56	60	63.54	72.66							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	4	7	23.58	60.02	86.04	141.06	75.42	80.26	87.86	131.74	141.06		
252	CLEARED TO START	2	2	9.24	99.6	101.54	106.9							
252	PUSHBACK AT 1420Z	1	2	11.92	103.56	110.66	119.78							
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	8	9.9	180.02	200.26	261.14	320.42	182.46	194.26	200.34	261.14	320.42	
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	9	11.16	326.2	330.68	338.66	381.22	440.5	501.3	329.74	341.7	381.22	440.5
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	7	13	13.5	539.62	543.32	554.5	560.58	621.38	680.66	741.46	547.36	557.54	560.58
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	8.88	854.18	856.36	860.02	867.62	920.82					
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									

321 KBOS ALTIMETER 30.02	2	2	14.62	60.02	62.86	65.72							
321 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	4	14.1	81.36	83.68	98.7	114.1	143.4					
321 KBOS ATIS CHARLIE CURRENT	1	2	8.76	100.04	103.88	111.26							
321 EXPECT TAXI TO TERMINAL E VIA L.B.Z	18	23	39.8	135.88	473.46	502.12	562.92	622.2	683	742.28	803.08	862.36	923.16
321 CONTACT BOS TOWER 128.8	1	3	10.32	1000.84	1003.94	1015.88	1043.24						
321 TAXI TO TERMINAL E VIA N.B.Z	2	3	33.48	1330.48	1337.22	1342.68	1368.52						
321 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	16.02	1378.9	1385.24	1398.92	1403.48						
322 CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322 KBOS ALTIMETER 30.02	1	2	9.8	60.02	62.72	72.52							
322 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	3	37.86	65	74.72	76.32	106.72						
322 KBOS ATIS CHARLIE CURRENT	1	2	17.16	100.04	110.06	121.92							
322 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	2	27.82	104.5	123.56	137.12							
322 CONTACT BOS TOWER 128.8	2	3	8.44	1032.76	1034.98	1035.44	1046.08						
322 TAXI TO TERMINAL E VIA N.B.Z	1	4	13.14	1360.7	1368.18	1378.96	1381.74	1395.68					
322 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	2	12.96	1443.38	1446.66	1461.04							
361 KBOS ATIS INDIA CURRENT	1	2	10.26	30.04	34.66	43.54							
361 CLEARED TO START	1	1	19.48	30.86	46.24								
361 PUSHBACK AT 2039Z	2	4	31.7	34.14	53.44	59.52	70.16	120.32					
361 KBOS ALTIMETER 29.90	1	2	109.86	60	165.48	173.52							
361 EXPECT TAXI TO RW 27 VIA A.C.D	2	4	83.28	60.02	68.22	120.32	144.96	179.6					
361 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	4	22.64	180.02	218.54	182.88	206.96	240.4					
361 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	5	7	17.04	262.72	294.54	299.68	360.48	419.76	265.32	312.5	360.48		
361 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	6	11	11.32	440.08	447.5	451.68	479.04	539.84	599.12	444.76	453.88	488.88	539.84
361 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	3	14.32	770.7	773.92	780	789.12						
362 CLEARED TO START	1	2	7.88	20.92	24.32	31.4							
362 PUSHBACK AT 1539Z	1	1	14.78	24.68	34.28								
362 KBOS ATIS INDIA CURRENT	2	3	52.68	30.04	42.56	56.24	86.64						
362 KBOS ALTIMETER 29.90	1	2	32.28	60	88.16	97.28							
362 EXPECT TAXI TO RW 27 VIA A.C.D	5	7	81.86	60.02	67.24	117.04	142.88	176.32	126.3	145.92	164.16		
362 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	3	4	7.74	180.02	219.46	237.12	181.88	191.52					
362 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	6	10	15.02	242.8	246.68	258.4	296.4	357.2	416.48	244.72	262.96	349.38	357.2
362 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	11	12.42	439.24	451.78	477.28	536.56	597.36	656.64	717.44	776.72	442.74	456
362 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	3	13.38	750.8	752.92	769.12	776.72						
431 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431 EXPECT TAXI TO TERMINAL B VIA E	4	5	13.16	211.18	226.86	242.58	214.54	222.04	228.9				
431 KBOS ALTIMETER 30.02	1	2	12.56	270.02	273.36	284.66							
431 EXPECT TAXI TO TERMINAL B VIA K.B.E	10	14	80.68	277.6	280.08	303.38	356.58	359.62	559.44	602.82	662.1	286.96	303.38
431 KBOS ATIS GOLF CURRENT	1	2	21.62	350.04	367	376.34							
431 CONTACT BOS TOWER 132.22	1	2	11.6	618.14	622.58	634.74							
431 TAXI TO TERMINAL B VIA K.B.A-2	2	3	25.52	899.72	917.68	921.1	929.62						
431 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	3	4	34.4	941.18	956.44	960.24	963.06	979.78					
432 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432 EXPECT TAXI TO TERMINAL B VIA E	7	8	9.96	235	240.34	243.06	246.1	268.9	276.5	237.1	243.06	249.14	
432 KBOS ALTIMETER 30.02	1	2	9.82	270.02	272.06	284.1							
432 EXPECT TAXI TO TERMINAL B VIA K.B.E	2	5	13.48	299.34	304	308.5	317.54	328.18	643.04				
432 KBOS ATIS GOLF CURRENT	1	2	9.42	350.04	354.34	364.66							
432 CONTACT BOS TOWER 132.22	1	3	16.6	658.48	661.32	680.82	688.42						
432 TAXI TO TERMINAL B VIA K.B.A-2	4	5	42.66	948.22	974.92	979.24	987.08	989.38	995.46				
432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	3	5	17.5	1000.76	1004.58	1013.66	1014.82	1022.82	1048.66				
471 KBOS ATIS KILO CURRENT	1	2	27.78	30.04	48.38	62.4							
471 KBOS ALTIMETER 30.04	1	2	16.08	60	67.78	80.64							
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	2	5	43.98	60.02	82.76	91.28	108	147.94	150.56				
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	10	11	88.14	120.04	153.52	157.12	171.42	176.9	200.72	208.32	211.36	512.94	192.14
471 CLEARED TO START	2	3	14.92	240.76	246.32	250.68	258.64						
471 PUSHBACK AT 1823Z	2	3	24.38	245.66	261.7	261.64	273.68						
471 TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	10	11	15.96	539.56	544.02	551.84	556.4	570.08	630.88	690.16	750.96	810.24	542.94
471 AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	7	11	20.5	819.72	874	930.32	991.12	1050.4	1111.2	824.06	834.28	843.86	871.04

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	6	8	16.36	1117.56	1125.54	1132.48	1134	1170.48	1119.96	1131.16	1138.56	1170.5	
472	CLEARED TO START	1	1	10.02	10.7	17.36								
472	PUSHBACK AT 1324Z	2	2	15.84	14.56	54.42	23.6							
472	KBOS ATIS KILO CURRENT	2	3	9.88	30.04	50.96	32.72	44.88						
472	KBOS ALTIMETER 30.04	2	3	17.96	60	69.38	72.24	81.44						
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	7	8	37.44	60.02	62.04	72.24	93.52	98.08	133.04	84.54	93.3	102.64	
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	9	10	11.14	120.04	136.02	192.32	253.12	275.38	312.4	373.2	432.48	123.92	128.18
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	7	11.96	336.12	482.34	493.28	552.56	613.36	338.52	343.14	353.44		
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	13	17	58.52	621.8	629.2	630.08	672.64	681.76	733.44	792.72	852	912.8	972.08
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	10.68	914.12	916.14	922.96	929.52	972.08					

Case	Avg Response Time
21x	11.23714286
25x	28.83375
32x	18.87714286
36x	34.87125
43x	22.78428571
47x	28.22125

Type	Avg Response Time
Info	20.06416667
Freq	10.44
PB/St	19.25333333
Exp	31.55083333
Taxi	19.22166667
Amd	24.90555556

Type	Avg FD Error
PBase	0.756220667
RBase	0.694310667
PRecv	1.612651167
RRecv	1.052200667
POth	1.624402917
ROth	0.999202667
Phi	1.753360875
Rhi	0.979366875
Pmed	1.315394125
Rmed	1.050389125
Plo	1.14450325
Rlo	0.7789315

Alt	Ave "Exp Taxi" Response by Altitude
16k	25.98
14k	33.81
10k	11.56
8k	47.08
7k	15.53
5k	8.94
Grnd	39.42

Alt	Ave "Info" Response Time by Altitude
High	12.59
Med	13.36
Low	9.31
Freq	10.44

K.3.5 Crew #5

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
102	228.019	0.881497	0.569261	0.244773	0.337342	0.25737	0.55503	12.8568
142	262.614							15.0199
212	208.675	1.0724	2.26249	2.79352	2.99336	1.02584	0.430105	13.6124
252	327.972							12.2145
322	248.632	0.651931	0.370887	0.612111	0.644417	0.249419	0.298491	12.3741
362	320.884							12.6368
432	155.708	0.362867	0.937623	0.631798	0.450611	0.49574	0.530774	12.6715
472	341.056							12.1866

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Time	...	Note: only time for first 9 views are shown				
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0								
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	3	3	218	60	178	211	264					
211	KBOS ALTIMETER 30.02	1	1	28	63	78							
211	EXPECT TAXI TO TERMINAL B VIA E	1	1	9	95	96							
211	KBOS ATIS ECHO CURRENT	1	2	11	104	110	230						
211	CONTACT BOS TOWER 132.22	1	1	11	657	663							
211	TAXI TO TERMINAL B VIA K.E-1	1	1	43	940	977							
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	1	28	991	997							
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0								
212	KBOS ALTIMETER 30.02	1	1	229.56	60.02	278.3							
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	32.1	60.76	68.18	91.16	97.24					
212	EXPECT TAXI TO TERMINAL B VIA E	1	2	18	96.76	108.84	391.58						
212	KBOS ATIS ECHO CURRENT	1	1	4	100.04	100.58							
212	CONTACT BOS TOWER 132.22	1	3	84.08	639.1	642.78	650.52	690.04					
212	TAXI TO TERMINAL B VIA K.E-1	1	3	61.68	905.22	938.28	951.48	971.24					
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	2	29.86	956.06	972.76	991						
251	KBOS ATIS HOTEL CURRENT	1	1	9	30	35							
251	KBOS ALTIMETER 29.96	1	1	11	60	67							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	3	3	130	60	76	109	176					
251	CLEARED TO START	1	1	5	276	277							
251	PUSHBACK AT 1817Z	1	1	13	281	284							
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	1	2	42	180	199	381						
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	2	13	518	522	626						
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	1	19	757	761							
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	1	41	1096	1098							
252	KBOS ATIS HOTEL CURRENT	1	2	6.92	30.04	33.24	41.4						
252	KBOS ALTIMETER 29.96	1	1	50.7	60	106.9							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	3	4	106.44	60.02	112.84	139.12	140.2	170.6				
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	8	123.56	180.02	182.76	201	273.14	301.56	309.64	321.08	380.36	443.8
252	CLEARED TO START	2	2	20.02	245.16	248.12	262.82						
252	PUSHBACK AT 1327Z	1	1	7.78	249.84	251.16							
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	6	13.76	452.3	454.84	471.02	500.44	561.24	620.52	681.32		
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	7	8	15.68	681.7	745.52	801.4	860.68	921.48	980.76	1040	685.88	704.06
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	46.1	991.86	1024.22	1041.56						
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0								
321	KBOS ALTIMETER 30.02	1	1	9	340	344							
321	KBOS ATIS CHARLIE CURRENT	1	1	9	421	424							
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	1	17	444	445							
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	1	16	516	522							
321	CONTACT BOS TOWER 128.8	1	1	15	981	987							
321	TAXI TO TERMINAL E VIA N.B.Z	1	1	33	1306	1321							
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	1	14	1385	1391							
322	CROSS PVD AT 11000 FT 250 KIAS	0	0		0								

322	KBOS ALTIMETER 30.02	1	1	9	340.04	344.9								
322	KBOS ATIS CHARLIE CURRENT	1	1	9.88	420.04	424.42								
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	3	25.76	435.76	439.46	467.22	473.68						
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	2	17.2	513.96	517.42	536							
322	CONTACT BOS TOWER 128.8	1	1	16.76	969.84	981.34								
322	TAXI TO TERMINAL E VIA N.B.Z	3	4	116.64	1288.44	1323.14	1373.52	1402.26	1410					
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	2	15.86	1379.26	1382.64	1416.9							
361	KBOS ATIS INDIA CURRENT	1	1	30	30	34								
361	KBOS ALTIMETER 29.90	1	1	19	60	73								
361	EXPECT TAXI TO RW 27 VIA A.C.D	1	1	33	63	82								
361	PUSHBACK AT 2149Z	1	1	10	176	178								
361	CLEARED TO START	1	1	17	178	192								
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	1	32	180	199								
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	1	1	19	406	409								
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	1	2	25	642	646	678							
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	1	37	949	952								
362	KBOS ATIS INDIA CURRENT	1	1	13.32	30.04	38.96								
362	KBOS ALTIMETER 29.90	1	1	14.04	60	70.98								
362	EXPECT TAXI TO RW 27 VIA A.C.D	1	2	24.44	60.02	75.64	89.32							
362	CLEARED TO START	1	1	8	124.9	128.84								
362	PUSHBACK AT 1633Z	1	2	16.7	129.06	134.92	150.12							
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	5	12.74	180.02	183.56	198.4	207.88	267.16	343.64				
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	4	8	14.92	379.92	538	568.12	384.2	387.24	400.6	448.04	507.32	568.12	
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	9	16.02	604.84	624.28	627.4	688.2	747.48	808.28	867.56	928.36	610.68	628.08
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	1	35.42	907	932.6								
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	1	1	9	307	309								
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	1	1	12	362	366								
431	KBOS ALTIMETER 30.02	1	1	8	410	413								
431	KBOS ATIS GOLF CURRENT	1	1	9	490	493								
431	CONTACT BOS TOWER 132.22	1	1	14	657	660								
431	TAXI TO TERMINAL B VIA K.B.A-2	1	1	60	938	975								
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	1	1	30	985	1004								
432	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432	EXPECT TAXI TO TERMINAL B VIA E	1	1	20.7	361.26	366.66								
432	KBOS ALTIMETER 30.02	1	2	13.6	410.04	414.88	428.12							
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	3	4	23.84	442.18	445.36	452.44	461.92	470.68					
432	KBOS ATIS GOLF CURRENT	1	2	8.78	490.04	492.74	502.6							
432	CONTACT BOS TOWER 132.22	1	1	14.16	609.38	616.48								
432	TAXI TO TERMINAL B VIA K.B.A-2	2	2	58.12	843.9	880.26	898.38							
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	20.4	898.28	906.92	912.68	923.64	931.24					
471	KBOS ATIS KILO CURRENT	1	1	10	30	35								
471	KBOS ALTIMETER 30.04	1	1	82	60	138								
471	EXPECT TAXI TO RW 33L VIA A.F.M.C	1	1	64	60	65								
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	1	1	47	120	145								
471	CLEARED TO START	1	1	5	228	230								
471	PUSHBACK AT 1931Z	1	1	11	232	237								
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	1	13	555	558								
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	1	1	34	887	901								
471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	1	40	1206	1236								
472	KBOS ATIS KILO CURRENT	1	2	7.18	30.04	34.38	42.3							
472	KBOS ALTIMETER 30.04	2	3	27.34	60	81.82	84.86	92.46						
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	2	3	14.92	60.02	66.7	72.64	78.78						
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	2	2	18.9	120.04	124.38	134.04							
472	CLEARED TO START	1	1	11.76	181.78	189.74								
472	PUSHBACK AT 1536Z	1	4	185.38	191.58	195.82	372.14	381.26	384.3					
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	3	8	16.06	491.48	495.26	502.14	504.38	511.98	565.18	624.46	685.26	744.54	
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	8	29.76	805.48	819.36	828.78	840.3	864.62	925.42	984.7	1045.5	1104.8	

472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	3	4	27.22	1145.48	1148.86	1164.06	1166.88	1177.7

Case	Avg Response Time
21x	57.66285714
25x	37.44222222
32x	23.15
36x	20.97777778
43x	21.54285714
47x	35.80666667

Type	Avg Response Time
Info	26.22166667
Freq	25.83333333
PB/St	25.88666667
Exp	44.48333333
Taxi	38.515
Amd	28.01777778

Alt	Ave "Exp Taxi" Response by Altitude
16k	32.10
14k	13.50
10k	21.38
8k	16.60
7k	14.85
5k	17.92
Grnd	54.08

Type	Avg FD Error
PBase	0.461213333
RBase	0.487211
PRecv	0.726750333
RRecv	1.145893667
POth	0.788779444
ROth	0.771412222
Phi	0.74217375
Rhi	1.03506525
Pmed	1.0705505
Rmed	1.1064325
Plo	0.50709225
Rlo	0.4536

Alt	Ave "Info" Response Time by Altitude
High	14.33
Med	9.22
Low	9.85
Freq	25.83

K.3.6 Crew #6

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
102	184.16	0.455676	0.233953	0.201129	0.340438	0.27849	0.33602	14.8845
103	239.66	0.69235	0.17058	0.20704	0.444768	0.385784	0.43273	14.7476
141	283.734							15.3572
142	241.81							15.1297
211	184.156	0.539686	0.591604	1.0273	0.753079	0.39779	0.47584	16.9401
212	202.968	0.739938	0.550844	0.496476	0.369728	0.482104	0.25548	16.3059
251	214.846							12.2867
252	286.018							12.4384
321	204.292	0.582156	0.21942	0.324736	0.21499	0.347728	0.54748	12.893
322	205.541	1.12642	0.181192	0.412081	0.557657	0.350187	0.31248	13.0681
361	347.017							12.5012
362	265.702							12.5651
431	175.097	0.32495	0.686255	0.350434	0.223986	0.338442	0.27656	17.6678
432	195.664	0.767921	0.690479	0.215962	0.333158	0.38433	0.32368	23.3802
471	346.633							13.6464
472	271.15							13.3037

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim ...		Note: only time for first 9 views are shown					
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	14.8	223.6	226.48	228.2	243.4						
211	KBOS ALTIMETER 30.02	1	3	10	270.02	272.32	284.44	289						
211	EXPECT TAXI TO TERMINAL B VIA E	1	7	8.78	296.26	298.28	308.76	634.56	649.24	708.52	769.32	828.6		
211	KBOS ATIS ECHO CURRENT	1	3	6.72	350.04	352.14	361.96	409.08						
211	CONTACT BOS TOWER 132.22	1	2	6.34	587.98	590.9	599.08							
211	TAXI TO TERMINAL B VIA K.E-1	1	3	10.32	860.8	865.08	875.72	889.4						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	9.22	907	909.16	921.32	948.68						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	28.32								
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	1	21.66	248.42	251.14								
212	KBOS ALTIMETER 30.02	1	3	11.36	270.02	273.86	286.02	310.34						
212	EXPECT TAXI TO TERMINAL B VIA E	1	2	8.62	309.88	313.48	324.02							
212	KBOS ATIS ECHO CURRENT	1	3	6	350.04	352.28	360.5	369.62						
212	CONTACT BOS TOWER 132.22	1	3	8.94	587.42	589.66	600.66	609.78						
212	TAXI TO TERMINAL B VIA K.E-1	1	3	13.4	873.16	879.8	890.98	909.22						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	9.36	918.18	923.92	932.02	970.02						
251	KBOS ATIS HOTEL CURRENT	1	2	7.92	30.04	33.56	42.68							
251	KBOS ALTIMETER 29.96	1	2	11.92	60	70.02	76.12							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	4	6	26.84	60.02	149.08	152.12	212.92	77.8	91.32	92.84			
251	CLEARED TO START	2	3	8.76	107.74	109.56	114.66	121.72						
251	PUSHBACK AT 2136Z	1	3	18.96	111.44	125.14	135.4	152.12						
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	5	23.18	180.02	215.24	272.2	333	182.52	208.36				
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	3	6	11.16	347.9	359.62	392.28	349.72	364.92	392.28	453.08			
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	4	7.84	548.6	551.16	561	573.16	612.22					
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	6.3	875.88	878.54	887.8							
252	KBOS ATIS HOTEL CURRENT	1	2	5.32	30.04	32.28	40.46							
252	KBOS ALTIMETER 29.96	1	2	10.7	60	66.9	73.42							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	1	2	26.04	60.02	80.56	90.62							
252	CLEARED TO START	1	2	5.3	135.34	137.74	145.34							
252	PUSHBACK AT 1518Z	1	1	14.24	140.08	148.3								
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	5	7	10.78	180.02	195.82	207.66	268.46	327.74	183.34	195.5	207.66		
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	5	9	9.64	344.96	356.98	387.02	447.82	507.1	347.5	359.66	387.02	447.82	507.1
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	8	11	7	539.5	564.22	567.9	627.18	687.98	747.26	808.06	867.34	541.18	594.08
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	6.88	872.94	875.18	884.06							

321 CROSS PVD AT 11000 FT 250 KIAS	1	1		0	202.84								
321 KBOS ALTIMETER 30.02	1	2	7.64	500.04	502.7	512.44							
321 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	11.42	586.1	589.14	602.12							
321 KBOS ATIS CHARLIE CURRENT	1	1	6.58	630.04	632.6								
321 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	1	7.94	700.86	703.3								
321 CONTACT BOS TOWER 128.8	1	2	7.74	901.42	903.66	913.72							
321 TAXI TO TERMINAL E VIA N.B.Z	1	3	7.16	1221.66	1223.9	1232.92	1292.2						
321 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	2	7.7	1295.84	1298.28	1308.92							
322 CROSS PVD AT 11000 FT 250 KIAS	2	2		0	10.28	27.42							
322 KBOS ALTIMETER 30.02	2	2	10.88	500.04	502.84	506.22							
322 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	3	8.78	562.06	564.94	567.02	574.62						
322 KBOS ATIS CHARLIE CURRENT	1	2	5.94	630.04	632.44	639.98							
322 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	3	7.4	659.84	662.78	671.9	687.1						
322 CONTACT BOS TOWER 128.8	1	3	7.02	894.08	897.68	905.98	927.26						
322 TAXI TO TERMINAL E VIA N.B.Z	1	3	6.82	1196.36	1198.78	1208.46	1226.7						
322 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	11.12	1259.46	1261.66	1275.34	1287.5						
361 KBOS ATIS INDIA CURRENT	1	2	10.98	30.04	33.62	44.84							
361 KBOS ALTIMETER 29.90	1	1	7.56	60	65.54								
361 EXPECT TAXI TO RW 27 VIA A.C.D	2	4	28.64	60.02	70.68	78.28	93.48	154.28					
361 CLEARED TO START	2	3	19.96	156.34	159.12	174.68	181.64						
361 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	5	12.6	180.02	184.68	222.48	257.64	318.44	459.8				
361 PUSHBACK AT 1832Z	1	2	7.62	205.12	207.48	216.6							
361 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	9	14	13.2	477.46	663	677.16	737.96	797.24	858.04	917.32	978.12	1037.4	479.56
361 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	1	7	11.12	700.08	702.48	716.68	737.96	797.24	858.04	917.32	978.12		
361 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	3	9.1	985.44	987.6	999.4	1037.4						
362 KBOS ATIS INDIA CURRENT	1	3	5.3	30.04	32.2	39.56	41.08						
362 KBOS ALTIMETER 29.90	1	1	7.28	60	65.26								
362 EXPECT TAXI TO RW 27 VIA A.C.D	1	2	14.76	60.02	68.44	79.08							
362 CLEARED TO START	2	3	5.74	97.98	100.36	101.88	107.96						
362 PUSHBACK AT 2202Z	1	3	17.1	101.5	111	123.16	161.16						
362 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	1	4	11.22	180.02	183.96	196.12	212.82	221.96					
362 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	4	6	12.34	379.1	474.38	521.4	582.2	381.56	396.76	401.32			
362 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	6	7	8.76	576.64	626.94	641.48	702.28	761.56	578.92	582.2	589.8		
362 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	2	5.88	887.08	889.04	896.84							
431 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431 EXPECT TAXI TO TERMINAL B VIA E	2	4	10.62	37.68	40.74	42.14	52.78	58.22					
431 KBOS ALTIMETER 30.02	1	1	9.86	60.02	61.9								
431 EXPECT TAXI TO TERMINAL B VIA K.B.E	2	5	11.44	74.46	76.42	82.38	90.78	101.42	240.44				
431 KBOS ATIS GOLF CURRENT	1	2	7.32	100.04	104.46	112.06							
431 CONTACT BOS TOWER 132.22	1	3	6.58	585.4	587.34	596.94	641.02						
431 TAXI TO TERMINAL B VIA K.B.A-2	2	4	13.92	860	864.46	871.28	878.14	881.18					
431 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	18.54	911.26	914.62	920.06	934.38	941.98					
432 CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	19.52								
432 EXPECT TAXI TO TERMINAL B VIA E	1	1	7.9	50.48	52.78								
432 KBOS ALTIMETER 30.02	1	2	10.7	60.02	61.9	75.58							
432 EXPECT TAXI TO TERMINAL B VIA K.B.E	2	4	11.16	90.26	92.3	98.46	105.98	646.9					
432 KBOS ATIS GOLF CURRENT	1	3	16.92	100.04	108.66	121.18	133.34						
432 CONTACT BOS TOWER 132.22	1	3	4.5	589	591.34	598.46	613.66						
432 TAXI TO TERMINAL B VIA K.B.A-2	2	4	8.64	871.12	874.84	877.4	884.22	913.1					
432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	13.08	928.14	931.34	933.74	946.54	973.9					
471 KBOS ATIS KILO CURRENT	1	2	7.42	30.04	32.56	42.62							
471 KBOS ALTIMETER 30.04	4	5	112.56	60	91.3	107.12	120.14	169.9	177.9				
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	1	3	9.96	60.02	63.9	74.54	75.58						
471 PUSHBACK AT 1931Z	1	1	8.18	111.68	114.06								
471 CLEARED TO START	1	1	12.08	116.6	126.22								
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	2	3	26.06	120.04	133.82	139	150.54						

471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	7	10.8	407.56	410.86	412.64	422.62	480.38	539.66	600.46	659.74		
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	7	9	15.02	703.34	789.06	839.1	899.9	959.18	1019.98	707.5	709.6	723.58	779.82
471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	10.3	985.56	988.1	990.84	1000.22	1019.98					
472	KBOS ATIS KILO CURRENT	1	2	7	30.04	32.54	40.64							
472	KBOS ALTIMETER 30.04	1	2	6.38	60	64.32	71.04							
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	2	4	25.8	60.02	72.84	83.12	90.8	92.32					
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	7	8	7.82	120.04	145.38	153.12	212.4	273.2	332.48	122	124.58	131.84	
472	CLEARED TO START	1	2	5.2	147.1	148.56	157.68							
472	PUSHBACK AT 1319Z	1	2	17.58	150.52	160.08	172.88							
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	9	10	8.14	439.3	453.96	513.36	572.64	633.44	692.72	752	812.8	442.1	443.76
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	5	6	7.66	719.84	869.34	872.08	932.88	722.06	724.52	760.54			
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	7.38	1017.3	1019.36	1021.4	1028.64	1052.26					

Case	Avg Response Time
21x	10.39428571
25x	13.67375
32x	8.152857143
36x	13.0725
43x	10.79857143
47x	19.08375

Type	Avg Response Time
Info	12.9275
Freq	6.853333333
PB/St	11.72666667
Exp	14.75916667
Taxi	10.46166667
Amd	9.57

Type	Avg FD Error
PBase	0.370078167
RBase	0.326414333
PRecv	0.659187333
RRecv	0.353943333
POth	0.43779475
ROth	0.453353667
Phi	0.653639625
Rhi	0.415540875
Pmed	0.40439475
Rmed	0.4047255
Plo	0.370606875
Rlo	0.370032375

Alt	Ave "Exp Taxi" Response by Altitude
16k	9.26
14k	11.30
10k	18.23
8k	8.70
7k	10.10
5k	7.67
Grnd	18.64

Alt	Ave "Info" Response Time by Altitude
High	11.20
Med	8.52
Low	7.76
Freq	6.85

K.3.7 Crew #7

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
101	397.637	3.44032	0.456148	0.688636	0.24992	0.627528	0.38803	11.4292
102	150.779	0.708581	1.19462	0.835541	1.04975	0.430558	0.93926	14.3735
141	185.315							16.1781
142	212.459							16.0484
211	193.023	1.32822	2.96724	0.685097	0.549655	0.655797	0.3837	15.6889
212	246.043	1.59235	4.54612	2.7097	0.626468	0.920993	7.48923	17.403
251	255.735							13.0711
252	216.997							12.2876
321	204.102	0.552336	0.447078	0.36583	0.525036	0.337563	0.42134	16.8298
322	191.947	0.585675	0.530364	0.325018	0.562784	0.302307	0.74855	13.2079
361	268.189							13.7017
362	235.451							13.7343
431	201.971	1.22196	1.75392	0.597747	0.823849	0.539793	0.68734	25.1126
432	139.786	1.67475	1.85609	0.536918	1.17404	0.71297	1.295	23.6156
471	283.943							15.048
472	360.175							11.9749

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim...	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	15.5	263.46	266.42	337.82							
211	KBOS ALTIMETER 30.02	1	2	19.2	270.02	281.62	293.78							
211	EXPECT TAXI TO TERMINAL B VIA E	1	1	13.34	342.12	346.98								
211	KBOS ATIS ECHO CURRENT	1	1	13.66	350.04	359.14								
211	CONTACT BOS TOWER 132.22	1	1	14.82	623.5	630.06								
211	TAXI TO TERMINAL B VIA K.E-1	2	3	30.7	896.4	914.92	916.98	932.18						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	4	6	23.04	947.38	951.26	971.7	976.26	951.94	974.74	976.26			
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	KBOS ALTIMETER 30.02	1	2	9.3	270.02	271.92	284.76							
212	KBOS ATIS ECHO CURRENT	2	3	25.68	350.04	352.42	366.84	380.52						
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	3	5.96	409.66	412.14	420.04	426.12						
212	EXPECT TAXI TO TERMINAL B VIA E	1	3	11.74	461.88	465.64	477.8	486.92						
212	CONTACT BOS TOWER 132.22	1	4	7.46	636.36	638.74	648.04	666.28	727.08					
212	TAXI TO TERMINAL B VIA K.E-1	1	3	18.3	919.52	931.46	942.92	967.24						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	9.44	978.54	982.44	991.56	1026.52						
251	KBOS ATIS HOTEL CURRENT	2	3	8.26	30.04	66.24	34.4	43.52						
251	KBOS ALTIMETER 29.96	1	1	15.44	60	72.62								
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	7	8	46.66	60.02	78.18	101.28	107.36	140.16	160.56	76.96	101.28	111.92	
251	CLEARED TO START	1	1	4.48	123.6	125.6								
251	PUSHBACK AT 2127Z	1	2	10.46	127.24	130.16	142.32							
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	7	10	13.14	180.02	188.28	194	221.36	280.64	341.44	357.74	182.52	198.56	221.36
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	10	10.46	361.08	365.06	371.84	400.72	460	520.8	362.72	376.4	400.72	460
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	8	10	12.9	558.66	573.56	580.08	640.88	700.16	760.96	820.24	881.04	560.92	575.52
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	3	4	13.34	889.06	898.36	903.84	891.54	906.88					
252	CLEARED TO START	1	1	6.74	8.86	10.88								
252	PUSHBACK AT 1503Z	4	4	10.7	11.52	21.2	23.04	107.04	18.48					
252	KBOS ATIS HOTEL CURRENT	1	3	7.18	30.04	33.68	42.8	51.92						
252	KBOS ALTIMETER 29.96	1	1	14.3	60	65.58								
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	6	9	25.06	60.02	84.56	85.36	110.16	111.2	172	77.76	89.92	111.2	172
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	3	3	18.34	180.02	199.12	231.28	193.28						
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	7	11	8.68	252.26	257.7	261.68	292.08	351.36	412.16	471.44	254.08	264.72	292.08
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	7	13	6.78	453.08	482.64	532.24	591.52	652.32	693.72	711.6	456.24	463.84	471.44
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	9.74	780.26	782.66	793.68							
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									

321	KBOS ALTIMETER 30.02	1	1	8.16	60.02	62.46								
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	2	38.7	64.72	70.22	79.34							
321	KBOS ATIS CHARLIE CURRENT	1	2	10.46	100.04	105.18	115.82							
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	2	2	28.68	122.36	126.22	138.62							
321	CONTACT BOS TOWER 128.8	1	2	14	985.36	987.82	995.9							
321	TAXI TO TERMINAL E VIA N.B.Z	1	2	7.82	1326.26	1328.78	1339.42							
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	7.34	1381.4	1383.5	1392.62	1398.7						
322	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	15.44	59.4	69.24	79.88							
322	KBOS ALTIMETER 30.02	1	1	7.38	60.02	64.22								
322	KBOS ATIS CHARLIE CURRENT	1	1	7.02	100.04	102.5								
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	1	9	119.52	122.16								
322	CONTACT BOS TOWER 128.8	1	1	10.44	959.12	961.7								
322	TAXI TO TERMINAL E VIA N.B.Z	1	3	6.28	1279.42	1282.2	1289.8	1336.92						
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	8.36	1338.24	1341.48	1350.6	1396.2						
361	KBOS ATIS INDIA CURRENT	1	2	8.62	30.04	32.76	42.76							
361	KBOS ALTIMETER 29.90	1	1	42.88	60	99.76								
361	EXPECT TAXI TO RW 27 VIA A.C.D	4	4	59.7	60.02	72.2	88.36	120.28	112.5					
361	CLEARED TO START	1	1	7.66	133.16	137								
361	PUSHBACK AT 2059Z	2	2	12.46	138.46	143.08	149.16							
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	5	10.74	180.02	336.22	182.6	194.76	208.44	269.24				
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	6	8	19.26	368.74	372.14	389.32	448.6	509.4	568.68	371.16	392.36	448.6	
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	7	8	11.82	579.6	603.52	629.48	688.76	748.04	808.84	868.12	582.24	596.04	
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	2	12.9	876.72	879.06	893.96							
362	CLEARED TO START	1	1	10.46	15.64	23.68								
362	PUSHBACK AT 1445Z	3	4	29.62	18.46	29.14	32.18	46.16	53.46					
362	KBOS ATIS INDIA CURRENT	2	2	9.72	30.04	44.84	35.22							
362	KBOS ALTIMETER 29.90	1	1	10.8	60	64.96								
362	EXPECT TAXI TO RW 27 VIA A.C.D	1	4	21.78	60.02	73.22	86.9	91.46	152.26					
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	3	6	9.84	180.02	190.24	211.54	185.7	194.82	208.66	211.54			
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	8	12	7.84	238.92	246.76	272.34	282.44	331.62	392.42	451.7	558.68	241.94	251.06
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	10	15	17.1	438.38	454.38	456.26	512.5	564.04	571.78	631.06	692.92	751.14	447.14
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	3	14.16	746.92	749.62	751.14	766.34						
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	2	3	11.3	384.42	386.94	392.96	400.78						
431	KBOS ALTIMETER 30.02	1	2	11.16	410.04	411.9	426.62							
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	3	8.54	467.04	469.92	473	479.82						
431	KBOS ATIS GOLF CURRENT	1	2	5.38	490.04	491.98	499.58							
431	CONTACT BOS TOWER 132.22	1	2	8.36	624.34	626.54	637.9							
431	TAXI TO TERMINAL B VIA K.B.A-2	2	4	20.32	882.74	895.66	899.3	908.46	935.82					
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	3	21.26	933.04	941.9	948.26	958.62						
432	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432	EXPECT TAXI TO TERMINAL B VIA E	2	2	9.28	337.12	339.86	343.4							
432	KBOS ALTIMETER 30.02	1	1	9.46	410.04	413.54								
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	6	7.74	420.06	422.66	425.1	431.78	772.42	790.5	849.78			
432	KBOS ATIS GOLF CURRENT	1	1	6.62	490.04	492.6								
432	CONTACT BOS TOWER 132.22	1	2	10.8	617.9	621.8	633.94							
432	TAXI TO TERMINAL B VIA K.B.A-2	2	4	25.82	871.28	890.82	894.04	902.98	909.06					
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	3	10.9	918.08	921.22	924.6	933.38						
471	KBOS ATIS KILO CURRENT	3	3	79.14	30.04	35.9	44.24	107.28						
471	KBOS ALTIMETER 30.04	1	1	13.84	60	71.18								
471	EXPECT TAXI TO RW 33L VIA A.F.M.C	6	6	39.94	60.02	88.46	101.22	134.66	195.46	76.9	87.5			
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	6	7	47.22	120.04	203.66	254.74	584.26	122.5	134.66	142.52	149.86		
471	CLEARED TO START	3	3	10.64	310.04	320.18	321.62	314.02						
471	PUSHBACK AT 2004Z	2	3	15.76	316.32	355.3	324.66	336.82						
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	11	30.7	663.94	930.4	975.22	1034.5	666.14	674.26	676.78	684.9	843.86	855.14
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	7	11	15.44	1007.22	1061.86	1095.3	1154.58	1215.38	1274.66	1010.18	1020.58	1051.9	1095.3

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	20.56	1241.94	1244.26	1259.76	1267.06						
472	CLEARED TO START	2	3	256.44	29.68	44.2	283.7	291.62						
472	KBOS ATIS KILO CURRENT	2	3	244.78	30.04	156.34	272.92	279.46						
472	PUSHBACK AT 1338Z	2	3	125	38.94	48.86	161.98	168.5						
472	KBOS ALTIMETER 30.04	1	1	62.9	60	120.82								
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	3	4	49.2	60.02	66.1	68.7	89.46	113.78					
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	13	15	15.66	120.04	127.02	133.54	136.58	150.26	185.82	209.54	266.14	270.34	284.2
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	8	10	8.32	382.92	393.68	449.7	510.5	569.78	629.06	385.3	388	390.42	396.5
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	3	11.64	680.88	683.68	689.74	697.46						
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	6	21.78	960.92	963.6	967.78	987.78	989.3	1050.1	1109.38			

Case	Avg Response Time
21x	15.58142857
25x	15.16625
32x	12.79142857
36x	19.835
43x	11.92428571
47x	66.81

Alt	Ave "Exp Taxi" Response by Altitude
16k	27.07
14k	18.84
10k	10.73
8k	12.54
7k	10.29
5k	8.14
Grnd	29.77

Type	Avg Response Time
Info	27.13916667
Freq	10.98
PB/St	41.70166667
Exp	22.1875
Taxi	16.20833333
Amd	13.80555556

Alt	Ave Response Time by Altitude
High	8.16
Med	16.96
Low	8.16
Freq	10.98

Type	Avg FD Error
PBase	1.121860667
RBase	0.712955167
PRecv	0.964261833
RRecv	0.689318
POth	0.821621083
ROth	1.937657917
Phi	1.388024
Rhi	1.7189475
Pmed	0.843060875
Rmed	0.69518775
Plo	0.565938625
Rlo	1.5440565

K.3.8 Crew #8

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
101	201.107	1.00787	0.521895	0.281426	0.352899	0.668577	0.33559	14.7154
102	237.111	1.36134	0.464337	0.491371	0.347617	0.350401	0.55268	12.5115
141	245.079							12.5647
142	291.636							14.4272
211	163.369	0.544823	1.6726	0.401316	0.530312	0.551398	0.7826	16.1522
212	179.835	0.705623	2.68238	1.05448	0.493167	0.894103	0.91013	16.8346
251	304.376							8.41255
253	259.472							12.7367
321	195.939	0.331458	0.377657	0.350792	0.317835	0.495866	0.48678	17.1931
322	239.347	0.976583	0.370853	0.482375	0.5211	0.85866	0.54063	12.6257
361	331.319							13.3616
362	241.599							13.1612
431	147.137	1.59511	0.581036	0.611144	0.309195	0.993753	0.37275	16.2777
432	153.602	1.30272	2.52814	0.485804	0.373358	0.658612	0.64141	16.8188
471	324.873							13.7021
472	296.818							13.7859

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim ...	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	3	3		0	67.4	76.88	136.16						
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	7	384.04	386.64	395.36							
211	KBOS ALTIMETER 30.02	1	3	21.3	410.04	415.08	435.6	437.12						
211	EXPECT TAXI TO TERMINAL B VIA E	1	2	15.24	446.14	451.12	466							
211	KBOS ATIS ECHO CURRENT	1	1	4.44	490.04	492.58								
211	CONTACT BOS TOWER 132.22	1	1	14.74	594.24	599.52								
211	TAXI TO TERMINAL B VIA K.E-1	1	2	28.2	858.36	863.9	892.5							
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	4	14.76	908	912.88	917.44	957.36	976.72					
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	3	6.58	407.16	409.8	417.78	423.86						
212	KBOS ALTIMETER 30.02	1	1	28.84	410.04	427.74								
212	KBOS ATIS ECHO CURRENT	1	2	31.98	490.04	518.1	525.7							
212	EXPECT TAXI TO TERMINAL B VIA E	1	2	10.72	491.36	496.02	507.46							
212	CONTACT BOS TOWER 132.22	1	3	23.48	590.5	597.14	607.78	618.42						
212	TAXI TO TERMINAL B VIA K.E-1	1	1	24.12	858.56	863.94								
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	2	13.52	901.04	904.82	919.38							
251	KBOS ATIS HOTEL CURRENT	2	2	9.02	30.04	99.34	35.3							
251	KBOS ALTIMETER 29.96	1	1	21.16	60	78.22								
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	5	6	47.08	60.02	103.8	107.78	147.3	84.98	86.5	112.34			
251	CLEARED TO START	2	2	658.98	153.06	163.42	810.02							
251	PUSHBACK AT 2035Z	1	2	36.22	157.2	166.08	189.86							
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	11	14	181.48	180.02	204.94	206.58	267.38	326.66	361.62	387.46	195.94	206.58	267.38
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	10	15	18.6	404.24	418.16	423.94	446.74	506.02	566.82	626.1	686.9	746.18	806.98
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	6	163.68	633.14	638.02	651.94	723.04	746.18	791.86	800.9			
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	5	18.04	932.22	938.26	955.94	959.54	986.34	1047.14				
253	KBOS ATIS HOTEL CURRENT	1	2	6.02	30.04	34.1	41.62							
253	KBOS ALTIMETER 29.96	1	1	5.18	60	63.68								
253	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	3	7	33.88	60.02	142.24	155.62	67.46	78.1	90.26	124.16	155.62		
253	CLEARED TO START	2	2	28.44	81.58	83.14	106.86							
253	PUSHBACK AT 1531Z	1	1	11.68	89.36	96.34								
253	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	6	7.66	180.02	196.14	216.42	275.7	183.98	192.1	216.42			
253	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	14	45.46	294.66	303.92	336.02	344.62	395.78	455.06	486.06	515.86	575.14	635.94
253	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	7	9.92	514.26	517.64	529.54	575.14	635.94	695.22	756.02	815.3		
253	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	10.9	822.64	830.16	838.1							
321	CROSS PVD AT 11000 FT 250 KIAS	1	1		0	11.12								

321 KBOS ALTIMETER 30.02	1	1	8.04	340.04	343.92								
321 KBOS ATIS CHARLIE CURRENT	2	3	11.34	420.04	422.9	428.8	435.56						
321 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	48.3	432.04	437.08	485.72							
321 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	6	14.6	526.34	530.84	545	599.72	1180.2	1200.12	1259.4			
321 CONTACT BOS TOWER 128.8	2	2	11.86	960.54	963.32	970.2							
321 TAXI TO TERMINAL E VIA N.B.Z	1	3	11.96	1291.34	1296.26	1308.04	1320.2						
321 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	17.76	1351.32	1355.7	1374.92	1379.48						
322 CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322 KBOS ALTIMETER 30.02	1	1	7.5	340.04	342.46								
322 KBOS ATIS CHARLIE CURRENT	2	3	9.38	420.04	422.66	426.42	433.9						
322 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	2	69.24	448.22	484.2	499.26							
322 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	1	23.12	524.62	527.8								
322 CONTACT BOS TOWER 128.8	2	8	30.54	966.54	970.02	978.06	1002.38	1038.86	1098.14	1158.94	1218.22	1279	
322 TAXI TO TERMINAL E VIA N.B.Z	1	1	16.9	1284.08	1294.98								
322 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	1	13.82	1348.44	1351.6								
361 KBOS ATIS INDIA CURRENT	9	10	23.36	30.04	47.58	54.56	106.24	165.52	226.32	285.6	41.48	45.44	51.2
361 KBOS ALTIMETER 29.90	1	1	20.2	60	78.06								
361 EXPECT TAXI TO RW 27 VIA A.C.D	1	1	27.5	60.02	83.44								
361 CLEARED TO START	2	2	10.08	113.14	116.88	120.34							
361 PUSHBACK AT 2059Z	1	2	15.08	117	126	136.64							
361 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	3	7	5.98	180.02	331.52	346.4	182.6	193.44	226.32	285.6	340.32		
361 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	8	12	23.86	384.52	396.56	405.68	408.72	466.48	525.76	585.04	387.28	405.68	413.58
361 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	9	15	17.98	585.82	598.64	604.8	645.84	705.12	765.92	825.2	886	945.28	590.76
361 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	3	10.82	892.5	900.04	908.8	945.28						
362 CLEARED TO START	1	1	6.48	14.22	17.84								
362 PUSHBACK AT 1550Z	2	2	10.24	20.44	23.92	26.96							
362 KBOS ATIS INDIA CURRENT	1	2	8.02	30.04	33.04	43.68							
362 KBOS ALTIMETER 29.90	2	3	63.8	60	101.94	121.34	128.8						
362 EXPECT TAXI TO RW 27 VIA A.C.D	4	5	52.6	60.02	150.02	159.2	65.12	109.74	116.64				
362 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	5	7	9.68	180.02	188.76	191.12	218.48	279.28	183.48	194.16	218.48		
362 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	6	9	6.48	296.24	311.4	338.56	399.36	458.64	519.44	299.38	306.64	338.56	399.36
362 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	13	8.64	513.42	525.38	578.72	638	698.8	758.08	818.88	516.06	519.44	527.04
362 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	2	11.26	804.22	811.1	820.4							
431 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431 EXPECT TAXI TO TERMINAL B VIA E	1	2	18.86	55.58	67.16	78.56							
431 KBOS ALTIMETER 30.02	1	1	35.86	60.02	90.12								
431 EXPECT TAXI TO TERMINAL B VIA K.B.E	1	2	15.08	94.86	103.08	113.52							
431 KBOS ATIS GOLF CURRENT	2	2	21.9	100.04	115.04	120.1							
431 CONTACT BOS TOWER 132.22	1	1	8	625.32	627.94								
431 TAXI TO TERMINAL B VIA K.B.A-2	2	4	54.64	910.34	958.64	961.68	969.28	979.1					
431 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	22.14	974.2	985.16	990.98	1001.2	1022.48					
432 CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	95.88								
432 KBOS ALTIMETER 30.02	2	2	12.92	60.02	62.38	67.06							
432 EXPECT TAXI TO TERMINAL B VIA E	1	1	16.2	67.8	75.18								
432 KBOS ATIS GOLF CURRENT	1	1	6.74	100.04	103.66								
432 EXPECT TAXI TO TERMINAL B VIA K.B.E	1	7	17.32	111.6	124.86	132.94	135.74	172.46	246.9	831.44	891.42		
432 CONTACT BOS TOWER 132.22	1	1	7.62	618.44	622.02								
432 TAXI TO TERMINAL B VIA K.B.A-2	3	5	21.58	902.68	914.22	917.24	922.14	929.42	952.22				
432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	5	11.4	950.34	954.2	955.86	965.9	985.56	1011.5				
471 KBOS ATIS KILO CURRENT	2	3	17.2	30.04	40.4	45.62	51.52						
471 KBOS ALTIMETER 30.04	5	5	119.74	60	135.92	141.2	175.84	181.66	176.46				
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	1	1	20.48	60.02	64.18								
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	13	14	40.9	120.04	142.56	160.96	184.66	202	261.28	322.08	381.36	442.16	501.44
471 CLEARED TO START	1	1	10.54	212.72	221.14								
471 PUSHBACK AT 1243Z	2	2	29.24	216.24	226.32	230.24							
471 TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	14	20	16.76	554.54	564.28	569.84	571.36	621.52	682.32	741.6	802.4	861.68	922.48
471 AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	6	11	14.3	860.28	1018.4	1041.04	1101.84	1161.12	865.3	870.48	883.7	922.48	981.76

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	20.08	1132.54	1146.38	1148.06	1158.9	1161.12					
472	KBOS ATIS KILO CURRENT	2	2	23.32	30.04	36.38	51.68							
472	KBOS ALTIMETER 30.04	1	2	30.54	60	88.3	95.52							
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	3	3	165.04	60.02	104.6	97.46	222.82						
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	7	10	39.48	120.04	161.1	217.12	278.56	337.2	396.48	457.28	135.92	145.68	156.28
472	CLEARED TO START	1	1	45.3	124.7	167.58								
472	PUSHBACK AT 1727Z	3	5	79.86	132.7	154.66	156.32	176.24	209.52	217.12				
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	8	12	8.78	455.46	466.68	516.56	577.36	636.64	697.44	756.72	457.48	462.62	469.44
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	8	12	10.98	755.56	804.46	816	876.8	936.08	996.88	1056.16	758.5	760.82	773.34
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	13.58	1033.46	1037.92	1044.22	1055.58	1056.16					

Case	Avg Response Time
21x	17.49428571
25x	82.0875
32x	21.02571429
36x	20.75375
43x	19.30428571
47x	44.1325

Alt	Ave "Exp Taxi" Response by Altitude
16k	17.53
14k	16.20
10k	58.77
8k	18.86
7k	6.79
5k	12.98
Grnd	52.65

Type	Avg Response Time
Info	22.825
Freq	16.04
PB/St	78.51166667
Exp	37.25083333
Taxi	23.11166667
Amd	22.42111111

Alt	Ave "Info" Response Time by Altitude
High	19.36
Med	9.07
Low	21.64
Freq	16.04

Type	Avg FD Error
PBase	0.6934975
RBase	0.429169667
PRecv	0.736033667
RRecv	0.464356833
POth	0.739868167
ROth	0.975482
Phi	0.978190875
Rhi	1.14986225
Pmed	0.5198385
Rmed	0.405685375
Plo	0.68392125
Rlo	0.57782025

K.3.9 Crew #

Case	FFT	PHi	RHi	PMed	RMed	PLo	RLo	Speed
101	204.922	0.575182	0.313794	0.298876	0.438866	0.216234	0.41883	12.6559
102	170.587	0.648066	0.287757	0.365042	0.730888	0.388771	0.35395	11.6256
141	261.918							13.1144
142	225.065							15.5803
211	182.3	0.467753	0.951648	0.364724	0.374298	0.365182	0.25437	13.9091
212	185.455	0.970387	0.42666	0.634192	0.375114	0.459808	0.35861	16.1036
251	219.512							12.9834
252	299.442							12.1359
321	392.666	0.335655	0.106159	0.244287	0.31465	0.485707	0.24303	13.9904
322	193.392	0.286419	0.25804	0.1644	0.51146	0.422535	0.48279	13.8907
361	245.086							13.5062
362	227.438							13.356
431	135.117	0.447639	0.369064	0.282333	0.359597	0.401205	0.21475	17.8822
432	151.496	0.329973	3.78655	0.588177	0.281747	0.418093	0.73063	17.4103
471	256.74							13.6023
472	244.825							13.7481

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim...	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	KBOS ALTIMETER 30.02	1	2	6.18	60.02	62.68	70.24							
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	25.86	63.24	82.4	94.56							
211	EXPECT TAXI TO TERMINAL B VIA E	5	10	6.74	96.84	421.36	427.44	486.72	546	98.72	379.36	427.44	486.72	546
211	KBOS ATIS ECHO CURRENT	3	4	149.56	100.04	105.2	126.48	246.34	254.16					
211	CONTACT BOS TOWER 132.22	1	3	8.32	611.12	614.4	623.52	666.08						
211	TAXI TO TERMINAL B VIA K.E-1	2	2	30.9	888.2	891.04	906.24							
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	6.64	940.02	942.72	951.84	967.04						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	1	11.12	52.28	57.1								
212	KBOS ALTIMETER 30.02	2	5	68.46	60.02	66.26	105.94	113.38	117.94	133.14				
212	EXPECT TAXI TO TERMINAL B VIA E	7	9	4.84	87.68	255.86	297.3	358.1	417.38	478.18	537.46	90.58	169.38	177.22
212	KBOS ATIS ECHO CURRENT	2	3	53.08	100.04	137.7	141.76	148.34						
212	CONTACT BOS TOWER 132.22	1	6	6.1	616.94	619.44	627.14	657.54	718.34	777.62	838.42			
212	TAXI TO TERMINAL B VIA K.E-1	4	5	14.82	884.96	929.9	958.5	893.14	898.06	903.78				
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	7.2	936.86	940.26	949.38	958.5						
251	KBOS ATIS HOTEL CURRENT	1	3	7.3	30.04	32.54	42.74	44.26						
251	KBOS ALTIMETER 29.96	1	2	6.06	60	63.22	71.62							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	2	3	104.62	60.02	76.6	103.54	168.9						
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	5	5	27.42	180.02	484.46	523.06	583.86	182.28	204.66				
251	PUSHBACK AT 1859Z	1	2	12.26	366.7	374.7	383.22							
251	CLEARED TO START	1	3	6.36	464.5	466.82	475.94	523.06						
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	5	9	18.28	585.56	633.4	643.14	703.94	763.22	589.94	611.66	643.14	703.94	763.22
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	6	8	9.12	797.78	809.6	824.02	883.3	944.1	1003.38	799.7	811.86	824.02	
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	2	23.8	1113.54	1126.14	1141.7							
252	KBOS ATIS HOTEL CURRENT	1	2	6.24	30.04	32.34	41.46							
252	KBOS ALTIMETER 29.96	1	1	10.58	60	68.16								
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	5	7	49.08	60.02	70.2	88.58	109.86	75.14	88.58	114.42	149.38		
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	4	31.54	180.02	329.66	388.02	187.38	208.66					
252	PUSHBACK AT 1323Z	1	2	29.3	190	213.22	277.34							
252	CLEARED TO START	1	3	7.52	291.38	293.78	302.9	328.74						
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	10	15.68	398.48	404.44	415.38	448.82	508.1	568.9	400.18	429.16	448.82	508.1
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	6	11	36.8	609.34	632.04	646.42	688.98	748.26	615.24	628.18	649.46	688.98	775.28
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	5	8	19.26	926.46	943.04	945.86	988.42	1049.22	929.14	950.42	988.42	1049.22	
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									

321	KBOS ALTIMETER 30.02	1	2	8.34	500.04	502.7	512.66							
321	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	29.36	525.54	528.38	559.78							
321	EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	10	17.28	601.62	605.38	623.62	725.34	739.14	798.42	994.08	1038.58	1099.38	1158.66
321	KBOS ATIS CHARLIE CURRENT	1	3	9.04	630.04	632.74	644.9	678.34						
321	CONTACT BOS TOWER 128.8	1	3	5.94	932.96	935.2	942.82	979.3						
321	TAXI TO TERMINAL E VIA N.B.Z	1	2	8.2	1266.66	1269.62	1278.74							
321	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	8.12	1324.98	1327.38	1338.02	1398.82						
322	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322	KBOS ALTIMETER 30.02	1	2	7.32	500.04	503.14	512.94							
322	EXPECT TAXI TO TERMINAL E VIA L.B.A-1	4	6	40.78	540.16	546.9	581.34	593.5	543.34	585.9	593.5			
322	EXPECT TAXI TO TERMINAL E VIA L.B.Z	8	8	20.56	617.58	629.12	639.1	654.3	713.58	774.38	833.66	894.46	623.6	
322	KBOS ATIS CHARLIE CURRENT	1	4	14.48	630.04	640.62	649.74	654.3	713.58					
322	CONTACT BOS TOWER 128.8	8	14	18.14	947.84	1019.58	1073.82	1133.1	1193.9	1253.18	1313.98	1373.26	960.26	970.46
322	TAXI TO TERMINAL E VIA N.B.Z	1	3	9.02	1268.88	1272.76	1282.06	1313.98						
322	AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	16.28	1329.78	1333.74	1351.98	1373.26						
361	KBOS ATIS INDIA CURRENT	2	3	4.86	30.04	122	31.98	39.58						
361	KBOS ALTIMETER 29.90	1	1	22.58	60	79.42								
361	EXPECT TAXI TO RW 27 VIA A.C.D	6	6	74.8	60.02	126.16	135.34	185.5	85.18	119.84	124.7			
361	PUSHBACK AT 2121Z	2	3	183.7	150.46	153.58	332.08	339.02						
361	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	6	7	19.62	180.02	199.04	200.7	244.78	304.06	182.46	185.5	203.74		
361	CLEARED TO START	1	3	7.14	252.8	255.42	264.54	304.06						
361	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	7	11	16.08	394.6	399.06	411.98	424.14	484.94	544.22	605.02	396.78	415.02	424.14
361	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	7	9	6.18	595.96	663.9	664.3	725.1	784.38	845.18	904.46	597.42	607.16	664.3
361	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	2	24.12	902.58	905	931.82							
362	KBOS ATIS INDIA CURRENT	1	1	7.34	30.04	35.02								
362	KBOS ALTIMETER 29.90	1	1	6	60	62.94								
362	EXPECT TAXI TO RW 27 VIA A.C.D	2	3	15.72	60.02	81.52	69.98	80.62						
362	PUSHBACK AT 1535Z	1	4	11.68	90.92	100.46	107.98	114.06	173.34					
362	EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	2	6	19.4	180.02	187.02	192.56	203.74	223.46	234.14	293.42			
362	CLEARED TO START	2	4	29.68	189.34	208.54	217	223.5	234.14					
362	TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	7	12	12.5	325	328.3	339.02	354.22	413.5	474.3	533.58	326.86	342.06	354.22
362	AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	8	21.58	543.38	552.94	565.5	594.38	670.84	714.46	775.44	833.02	547.26	
362	AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	3	5	5.1	832.98	847.06	893.82	835.36	843.66	893.82				
431	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431	EXPECT TAXI TO TERMINAL B VIA E	2	3	12.6	237.9	241.44	246.7	255.3						
431	KBOS ALTIMETER 30.02	2	3	8.62	270.02	272.44	273.54	282.66						
431	EXPECT TAXI TO TERMINAL B VIA K.B.E	2	9	9.9	316.14	319.14	322	329.78	334.34	681.1	693.06	753.86	813.14	873.94
431	KBOS ATIS GOLF CURRENT	2	7	18.2	350.04	360.18	364.66	373.86	393.62	454.42	513.7	574.5		
431	CONTACT BOS TOWER 132.22	2	3	12.06	619.56	623.14	626.84	636.82						
431	TAXI TO TERMINAL B VIA K.B.A-2	2	4	20.22	898	907.38	914.08	922.58	933.22					
431	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	4	6	32.66	946.74	949.94	951.56	973.4	978.2	984.9	994.02			
432	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432	EXPECT TAXI TO TERMINAL B VIA E	5	6	9.2	239.46	247.02	249.68	296.8	241.9	245.48	252.72			
432	KBOS ALTIMETER 30.02	1	3	8.34	270.02	272.7	283.12	296.8						
432	EXPECT TAXI TO TERMINAL B VIA K.B.E	14	20	76.1	314.64	338.54	390.54	391.04	416.88	476.16	536.96	669.32	716.32	777.12
432	KBOS ATIS GOLF CURRENT	2	3	13.14	350.04	354.56	356.08	368.24						
432	CONTACT BOS TOWER 132.22	1	3	8.42	615.44	618.32	628.16	657.04						
432	TAXI TO TERMINAL B VIA K.B.A-2	4	6	9.82	898	919.34	956.48	900.24	903.28	912.4	956.48			
432	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	5	6	11.52	963.46	969.1	971.68	976.24	967.88	971.02	979.28			
471	KBOS ATIS KILO CURRENT	3	4	18.34	30.04	37.86	39.38	41.28	53.06					
471	KBOS ALTIMETER 30.04	2	2	52.6	60	107.78	109.76							
471	EXPECT TAXI TO RW 33L VIA A.F.M.C	3	3	65.72	60.02	103.54	118.42	122.68						
471	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	9	12	19.08	120.04	145.36	159.46	220.26	279.54	460.24	511.34	519.7	129.06	132.82
471	PUSHBACK AT 1954Z	4	5	11.24	247.46	290.26	340.34	399.62	252.18	262.82				
471	CLEARED TO START	1	3	11.24	345.32	349.46	361.62	399.62						
471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	11	16	9.22	553.86	558.56	559.22	563.78	580.5	639.78	699.06	759.86	819.14	879.94
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	4	5	16.58	839.78	888.12	939.22	850.92	853.82	861.7				

471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	17.12	1131.86	1140.02	1143.44	1153.54	1179.38						
472	KBOS ATIS KILO CURRENT	1	2	12.06	30.04	32.96	46.96								
472	KBOS ALTIMETER 30.04	1	1	17.66	60	70.56									
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	6	7	29.28	60.02	64.24	86.48	89.52	84.58	85.68	86.48	94.08			
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	6	9	13.14	120.04	126.96	133.6	143.18	147.28	122.96	125.58	138.16	147.28	210.56	
472	PUSHBACK AT 1415Z	1	2	6.86	178.56	182.24	189.84								
472	CLEARED TO START	1	3	4.3	276.2	278	285.6	326.64							
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	11	16	10.74	491.06	493.84	499.56	502.96	506	566.8	626.08	686.88	746.16	806.96	
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	6	12	9.28	784.28	845.86	866.24	927.04	986.32	787.2	789.16	797.84	806.96	866.24	
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	4	6	16.76	1069.06	1092	1106.4	1072.96	1082.3	1089.68	1106.4				

Case	Avg Response Time
21x	28.55857143
25x	26.32625
32x	15.20428571
36x	30.505
43x	17.91428571
47x	21.32625

Alt	Ave "Exp Taxi" Response by Altitude
16k	35.07
14k	18.92
10k	10.9
8k	43
7k	18.49
5k	5.79
Grnd	39.12

Type	Avg Response Time
Info	22.34916667
Freq	9.83
PB/St	26.77333333
Exp	30.57333333
Taxi	14.62333333
Amd	16.00666667

Alt	Ave "Info" Response Time by Altitude
High	9.80
Med	12.08
Low	69.32
Freq	9.83

Type	Avg FD Error
PBase	0.415361833
RBase	0.424014833
PRecv	0.406714667
RRecv	0.343164667
POth	0.43568175
ROth	0.69501475
Phi	0.50763425
Rhi	0.812459
Pmed	0.367753875
Rmed	0.4233275
Plo	0.394691875
Rlo	0.38212025

K.3.10 Crew #10

Case	FFT	PHi	RHi	PMed	RMed	PLo	RLo	Speed
101	197.43	2.28862	1.04721	0.387378	0.557508	0.521326	0.38631	13.6142
102	104.722	0.935831	0.363565	0.435728	0.652417	0.472687	0.709756	15.4245
141	129.382							11.1302
142	98.731							15.4876
211	112.697	1.2854	0.291059	1.2495	0.650507	1.20485	0.217126	17.7172
212	88.2721	0.519624	0.963905	0.708114	1.242	0.690649	3.57716	18.1262
252	156.772							11.9679
253	123.76							12.3145
321	120.09	0.449281	0.35068	0.681131	0.403871	2.14916	0.559876	12.4918
322	135.864	0.944724	0.242718	0.287441	1.2306	0.424897	0.641675	18.0573
361	227.19							12.0663
362	137.067							12.0699
431	77.063	2.66127	0.270464	0.310342	0.409078	0.708887	0.289482	18.8726
432	122.614	1.00636	0.864797	0.479307	0.209637	0.597723	0.501665	16.7941
471	184.213							11.2857
472	152.971							11.9691

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Time	...	Note: only time for first 9 views are shown					
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	2	3	19.9	341.04	343.96	357.54	362.78						
211	KBOS ALTIMETER 30.02	2	2		410.04	412.22	416.16							
211	EXPECT TAXI TO TERMINAL B VIA E	1	2	10.9	425.38	429.6	437.38							
211	KBOS ATIS ECHO CURRENT	1	1	10.42	490.04	492.1								
211	CONTACT BOS TOWER 132.22	1	2	29	621.48	636.4	652.38							
211	TAXI TO TERMINAL B VIA K.E-1	1	3	27.8	907.18	927.46	936.36	955.76						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	3	15.92	953.18	957.28	959.48	970.2						
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	KBOS ALTIMETER 30.02	2	3	8.46	410.04	412.3	413.38	419.82						
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	3	4	180.9	425.26	427.42	474.18	604.04	607.74					
212	KBOS ATIS ECHO CURRENT	1	2	14.54	490.04	492.44	507.4							
212	EXPECT TAXI TO TERMINAL B VIA E	2	10	62.02	527.78	530.1	533.86	538.7	561.14	574.86	582.1	586.86	592.28	594.26
212	CONTACT BOS TOWER 132.22	1	2	17.7	610.68	615.8	633.78							
212	TAXI TO TERMINAL B VIA K.E-1	1	3	28.72	884.54	909.32	914.88	930.5						
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	3	9.34	931.3	934.7	941.86	954.5						
252	KBOS ATIS HOTEL CURRENT	3	4	16.04	30.04	45.12	47.6	43.14	47.24					
252	PUSHBACK AT 2159Z	1	2	9.86	58.88	65.62	70.24							
252	KBOS ALTIMETER 29.96	1	2	14.96	60	72.6	76.46							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	3	7	25.5	60.02	149.16	163.12	78.2	86.86	90.66	101.2	102.32		
252	CLEARED TO START	1	2	46.54	61.7	104.04	110.2							
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	5	7	10.72	180.02	189.6	192	222.4	283.2	183.6	192.24	251.28		
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	9	8.8	295.24	306.22	342.48	403.28	462.56	523.36	297.66	306.3	342.48	403.28
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	5	9	24.7	512.18	539.24	582.64	643.44	514.56	523.36	540.22	542.76	582.64	668.22
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	3	38.06	850.7	864.42	882.08	891.08						
253	KBOS ATIS HOTEL CURRENT	2	3	202.52	30.04	42.96	230.12	234.68						
253	PUSHBACK AT 1549Z	1	2	32.52	36.58	64.94	74.22							
253	CLEARED TO START	1	2	49.22	42.36	85.64	92.74							
253	KBOS ALTIMETER 29.96	1	2	39.24	60	96.02	100.62							
253	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	1	3	45.22	60.02	102.82	106.34	160.86						
253	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	1	3	10.84	180.02	187.86	192.06	204.94						
253	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	1	5	10.7	240.54	243.28	252.84	280.94	340.22	401.02				
253	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	1	7	26.12	458.46	463.52	485.78	521.1	580.38	641.18	700.46	761.26		
253	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	4	16.14	768.54	782.08	785.9	820.54	880.8					
321	CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
321	KBOS ALTIMETER 30.02	1	2	9.04	60.02	66.16	70.44							

321 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	3	30.24	62.74	72.58	93.96	94.78						
321 KBOS ATIS CHARLIE CURRENT	1	2	8.22	100.04	102.18	109.06							
321 EXPECT TAXI TO TERMINAL E VIA L.B.Z	23	26	21.92	122.72	177.7	214.86	274.14	334.94	394.22	455.02	514.3	575.1	634.38
321 CONTACT BOS TOWER 128.8	1	3	12.66	955.52	958.42	970.02	994.62						
321 TAXI TO TERMINAL E VIA N.B.Z	1	3	8.12	1281.52	1284.56	1292.7	1294.06						
321 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	2	4	16.9	1347.28	1350	1354.86	1365.36	1414.14					
322 CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322 KBOS ALTIMETER 30.02	1	2	14.86	60.02	71.88	76.38							
322 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	20.74	68.46	85.38	91.26							
322 KBOS ATIS CHARLIE CURRENT	1	3	8.98	100.04	105.74	110.4	121.68						
322 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	7	12.4	126.9	136.18	140.96	702.74	722.08	1016.38	1021.5	1082.3		
322 CONTACT BOS TOWER 128.8	1	2	26.5	956.56	973.26	983.82							
322 TAXI TO TERMINAL E VIA N.B.Z	1	3	32.56	1286.7	1315.86	1320.36	1322.48						
322 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	2	8.94	1347.18	1350.98	1358.24							
361 KBOS ATIS INDIA CURRENT	1	2	48.16	30.04	72.96	79.98							
361 KBOS ALTIMETER 29.90	1	2	30.36	60	86.9	92.34							
361 EXPECT TAXI TO RW 27 VIA A.C.D	1	5	42.92	60.02	95.68	105.02	115.36	170.16	174.64				
361 PUSHBACK AT 1929Z	1	2	14.76	129.48	133.6	147.74							
361 CLEARED TO START	2	3	10.3	146.78	150.28	155.12	159.1						
361 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	5	8	15.64	180.02	308.8	354	414.8	183.76	192.6	197.78	235.44	294.72	
361 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	7	9	29.6	410.58	421.16	440.64	474.08	534.88	594.16	654.96	429.22	441.86	474.08
361 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	10	12	21.14	651.22	667.54	673.2	714.24	775.04	834.32	895.12	954.4	653.5	654.96
361 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	2	5	38	961.28	963.7	975.64	1000.62	1009.26	1015.2				
362 KBOS ATIS INDIA CURRENT	1	2	25.94	30.04	50.22	57.72							
362 PUSHBACK AT 1351Z	1	2	74.2	31.44	102.66	107.14							
362 CLEARED TO START	1	2	42.2	34.66	74.56	77.9							
362 KBOS ALTIMETER 29.90	1	2	23.78	60	81.06	85.18							
362 EXPECT TAXI TO RW 27 VIA A.C.D	3	4	34.26	60.02	150.56	163.14	88	96.02					
362 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	3	5	33.04	180.02	217.5	222.42	207.88	214.82	222.42				
362 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	7	12	10.28	258.6	268.02	269.54	283.22	342.5	403.3	462.58	260.28	270.5	283.22
362 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	13	7.92	480.86	520.32	523.38	582.66	643.46	702.74	762.02	822.82	485.62	490.18
362 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	2	43.12	794.38	828.84	838.88							
431 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
431 EXPECT TAXI TO TERMINAL B VIA E	2	3	11.74	249.7	253.76	257.64	266.52						
431 KBOS ALTIMETER 30.02	2	2	11.9	270.02	272.6	280.2							
431 EXPECT TAXI TO TERMINAL B VIA K.B.E	3	7	21.84	330.94	334.66	339.48	344.3	356.12	492.88	501.24	702.06		
431 KBOS ATIS GOLF CURRENT	1	3	14.84	350.04	359.46	369.88	375.96						
431 CONTACT BOS TOWER 132.22	1	2	11.94	648.16	650.68	664.76							
431 TAXI TO TERMINAL B VIA K.B.A-2	2	3	36.28	920.4	947.96	951.26	964.36						
431 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	2	21.8	973.62	985.48	988.28							
432 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432 EXPECT TAXI TO TERMINAL B VIA E	2	3	12.94	258.4	261.3	268.12	273.48						
432 KBOS ALTIMETER 30.02	2	3	282.7	270.02	276.94	549.5	554.96						
432 KBOS ATIS GOLF CURRENT	1	4	158.86	350.04	352.4	363.16	506.24	513.64					
432 EXPECT TAXI TO TERMINAL B VIA K.B.E	2	5	168.7	354.34	367.92	369.78	392.04	517.54	526.48				
432 CONTACT BOS TOWER 132.22	1	2	18.6	614.84	617.1	634.82							
432 TAXI TO TERMINAL B VIA K.B.A-2	2	3	26.56	884.86	906.26	908.52	916.44						
432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	12.3	930.48	936.54	938.16	946.84	949.88					
471 KBOS ATIS KILO CURRENT	1	3	10.74	30.04	33.58	41.86	44.22						
471 KBOS ALTIMETER 30.04	1	1	14.32	60	67.46								
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	2	2	25.2	60.02	77.66	79.46							
471 PUSHBACK AT 2036Z	1	2	8.98	104.68	108.06	115.34							
471 CLEARED TO START	1	2	13.52	108.14	117.86	123.46							
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	8	13	28.22	120.04	146.06	164.3	223.58	284.38	366.32	404.46	126.18	135.92	143.02
471 TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	10	14	14.16	437.66	448.3	453.1	463.74	523.02	583.82	643.1	703.9	763.18	443.98
471 AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	10	12	20.28	768.34	801.58	823.98	883.26	944.06	1003.34	1064.1	1123.4	1184.2	778.88
471 AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	3	4	42.28	1111.96	1115.44	1123.42	1151.94	1158.86					
472 KBOS ATIS KILO CURRENT	1	2	20.32	30.04	42.46	52.46							
472 KBOS ALTIMETER 30.04	1	2	37.84	60	95.24	99.32							

472	EXPECT TAXI TO RW 33L VIA A.F.M.C	2	3	50.56	60.02	105.04	107.4	112.24						
472	PUSHBACK AT 1449Z	1	2	18.84	67	81.98	87.56							
472	CLEARED TO START	1	2	6.2	70	74.08	78.16							
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	2	5	10.2	120.04	122.4	123.78	135.48	161.32	222.12				
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	14	21	7.1	379.6	387.6	401.48	462.28	521.56	582.36	641.64	702.44	761.72	821
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	2	4	25.92	685.28	706.36	708.52	716.12	761.72					
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	2	4	15.96	957.6	960.84	971.82	977.56	1001.88					

Case	Avg Response Time
21x	33.50923077
25x	39.23125
32x	16.57714286
36x	34.10125
43x	57.92857143
47x	23.165

Alt	Ave "Exp Taxi" Response by Altitude
16k	25.49
14k	17.16
10k	12.34
8k	95.27
7k	100.40
5k	36.46
Grnd	27.69

Type	Avg Response Time
Info	44.65391304
Freq	19.4
PB/St	27.26166667
Exp	37.77333333
Taxi	20.05666667
Amd	22.49111111

Alt	Ave "Info" Response Time by Altitude
High	10.28
Med	117.08
Low	11.14
Freq	19.40

Type	Avg FD Error
PBase	0.840261667
RBase	0.619461
PRecv	0.7763715
RRecv	0.546175333
POth	0.975035917
ROth	0.803270667
Phi	1.26138875
Rhi	0.54929975
Pmed	0.567367625
Rmed	0.66945225
Plo	0.846272375
Rlo	0.86038125

K.3.11 Crew #11

Case	FFT	PHI	RHI	PMed	RMed	PLo	RLo	Speed
101	326.967	0.31485	0.175074	0.337139	0.150345	0.47006	0.29913	11.859
102	191.233	2.89994	0.225284	0.257157	0.31347	0.29315	0.31506	12.214
141	261.912							16.495
142	204.672							16.277
211	187.905	0.787324	0.851073	0.451863	0.181895	0.33657	0.15159	13.517
212	180.48	0.545211	0.415861	0.211427	0.155085	0.201588	0.13304	19.154
251	326.112							12.691
252	283.814							12.607
321	228.51	7.03475	0.24305	0.877823	0.317223	0.443744	0.25839	12.635
322	205.663	1.57027	0.390199	0.313068	0.550529	0.15278	0.23766	14.78
361	275.242							13.708
362	288.451							13.765
431	216.065	3.82082	0.313658	1.20558	0.131309	0.851445	0.22545	19.226
432	165.914	0.554198	0.61896	0.736055	0.172337	0.948248	0.17525	21.943
471	361.128							13.913
472	290.506							13.27

Case	Msg	#Early Views	#Total Views	Resp Time	Recv Time	View Time	View Tim ...	Note: only time for first 9 views are shown						
211	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
211	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	10.04	48.5	50.92	61							
211	KBOS ALTIMETER 30.02	1	2	13.38	60.02	63.72	75.08							
211	EXPECT TAXI TO TERMINAL B VIA E	1	2	12.4	86.84	89.54	101.72							
211	KBOS ATIS ECHO CURRENT	1	3	13.04	100.04	105.12	119.02	149.42						
211	CONTACT BOS TOWER 132.22	2	3	22.36	585.84	589.24	604.18	613.02						
211	TAXI TO TERMINAL B VIA K.E-1	1	3	12.82	827.64	833.82	845.58	869.9						
211	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	2	4	14.18	880.18	885.1	889.58	898.78	929.18					
212	CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
212	EXPECT TAXI TO TERMINAL B VIA E.M.C.A	1	2	14.82	41.56	46.04	57.58							
212	KBOS ALTIMETER 30.02	1	2	9.14	60.02	66.58	70.78							
212	EXPECT TAXI TO TERMINAL B VIA E	3	5	18.1	63.7	280.98	73.1	76.46	85.58	319.76				
212	KBOS ATIS ECHO CURRENT	1	3	5.12	100.04	102.3	109.9	135.74						
212	CONTACT BOS TOWER 132.22	1	1	10.7	594.36	600.44								
212	TAXI TO TERMINAL B VIA K.E-1	1	2	8.8	851.62	855.58	865.34							
212	AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.B.E	1	2	7.5	902.58	906.38	915.5							
251	KBOS ATIS HOTEL CURRENT	2	3	13.74	30.04	34.48	38.88	48.1						
251	KBOS ALTIMETER 29.96	1	2	23.92	60	80.74	84.58							
251	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	1	2	40.2	60.02	88.22	102.08							
251	CLEARED TO START	1	2	48.6	63.56	109.58	113.32							
251	PUSHBACK AT 1841Z	1	2	52.5	72.22	118.28	127.38							
251	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	5	9	31.44	180.02	304.64	346.02	406.82	195.92	201.6	213.06	227.46	286.74	346.02
251	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	10	18.6	375.4	439.74	466.1	526.9	586.18	380.98	384.36	395.56	406.82	466.1
251	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	2	7	15.52	606.1	608.52	611.94	623.52	646.98	706.26	788.6	826.34		
251	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	4	9.42	903.38	906.28	915.74	946.42	1007.22					
252	KBOS ATIS HOTEL CURRENT	2	3	28.3	30.04	35.72	55.64	59.68						
252	KBOS ALTIMETER 29.96	1	2	5.2	60	61.8	66.3							
252	EXPECT TAXI TO RW 33L VIA A.Z.B.F.M.C	2	4	14.94	60.02	67.98	73.18	79.26	133.98					
252	EXPECT TAXI TO RW 33L VIA A.A-1.B.Q.M.F.H.RW22L.C	4	7	30.2	180.02	380.16	433.42	185.4	201.96	211.94	432.72	433.42		
252	CLEARED TO START	2	3	14.88	223.08	360.46	235.12	239.22						
252	PUSHBACK AT 1300Z	2	3	21.56	225.62	357.16	241.34	248.68						
252	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	6	11	11.82	449.16	469.52	494.22	553.5	614.3	673.58	451.46	465.34	467.66	494.22
252	AMENDED CLEARANCE TAXI TO RW 33L VIA A.F.M.C HOLD SHORT RW 27	10	14	20.64	685.68	730.54	734.38	793.66	854.46	913.74	973.02	1033.8	1093.1	690.26
252	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	5	11.42	977.14	979.74	992.6	995.76	1033.82	1093.1				

321 CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
321 KBOS ALTIMETER 30.02	1	2	9.58	340.04	344.26	353.54							
321 KBOS ATIS CHARLIE CURRENT	1	4	38.08	420.04	422.78	432.58	440.18	459.9					
321 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	1	2	51.88	438.24	481.22	494.9							
321 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	3	13.62	499.44	502.4	515.2	1090.86						
321 CONTACT BOS TOWER 128.8	1	1	9.82	948.78	953.06								
321 TAXI TO TERMINAL E VIA N.B.Z	1	2	7.2	1244.88	1247.18	1291.24							
321 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	5	13.62	1316.36	1320	1332.8	1338.74	1340.02	1399.3				
322 CROSS PVD AT 11000 FT 250 KIAS	0	0		0									
322 KBOS ALTIMETER 30.02	1	2	6.68	340.04	342.5	348.32							
322 EXPECT TAXI TO TERMINAL E VIA L.B.A-1	2	4	13.02	414.24	416.58	419.82	428.3	1195.2					
322 KBOS ATIS CHARLIE CURRENT	1	3	12.82	420.04	430.32	437.92	453.12						
322 EXPECT TAXI TO TERMINAL E VIA L.B.Z	1	3	13.58	490.2	493.34	506.08	1199						
322 CONTACT BOS TOWER 128.8	3	3	42.82	907.8	910.12	917.82	948.9						
322 TAXI TO TERMINAL E VIA N.B.Z	1	4	5.68	1212.28	1214.44	1220.32	1223.68	1232.88					
322 AMENDED CLEARANCE TAXI TO TERMINAL E VIA B.L.A	1	3	13.2	1269.8	1273.6	1287.6	1292.16						
361 KBOS ATIS INDIA CURRENT	1	2	30.74	30.04	58.94	62.68							
361 KBOS ALTIMETER 29.90	1	2	9.5	60	67.02	71.28							
361 EXPECT TAXI TO RW 27 VIA A.C.D	1	2	20.14	60.02	72.78	85.76							
361 CLEARED TO START	1	2	9.38	165.16	171.66	175.94							
361 PUSHBACK AT 2155Z	1	2	14.24	168.78	178.46	184.4							
361 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	3	5	12.14	180.02	289.06	305.36	186.32	363.38	365.44				
361 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	5	10	10.38	400.56	425.88	485.52	546.32	605.6	404.26	415.6	426.24	485.52	546.32
361 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	7	12	30.4	601.38	668.4	725.68	786.48	845.76	905.04	965.84	607.22	633.9	681.6
361 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	4	11.7	908.54	910.84	922.66	924.92	965.84					
362 KBOS ATIS INDIA CURRENT	1	2	20.62	30.04	47.36	52.5							
362 KBOS ALTIMETER 29.90	1	2	4.78	60	62.94	65.82							
362 EXPECT TAXI TO RW 27 VIA A.C.D	1	2	11.7	60.02	67.44	75.46							
362 CLEARED TO START	1	2	14.36	141.66	153.76	156.88							
362 PUSHBACK AT 1603Z	1	2	22.26	145.68	163.38	169.56							
362 EXPECT TAXI TO RW 27 VIA A.Q.M.C.D	7	9	13.92	180.02	199.38	200.1	260.9	320.18	380.98	395.88	182.36	198.58	200.1
362 TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L	6	11	9.06	416.28	431.68	440.26	501.06	560.34	621.14	418.52	429.62	440.26	501.06
362 AMENDED CLEARANCE TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L	8	14	11.58	639.72	670.34	680.42	700.18	741.22	800.5	861.3	920.58	643.56	652.84
362 AMENDED CLEARANCE TAXI TO RW 27 VIA D HOLD SHORT RW 27	1	4	5.24	924.26	926.28	934.26	981.38	1040.66					
431 CROSS SCUPP AT 11,000 FT 230 KIAS	1	1		0	311.44								
431 EXPECT TAXI TO TERMINAL B VIA E	2	4	12.08	339.92	343.3	350	353.56	360.94					
431 EXPECT TAXI TO TERMINAL B VIA K.B.E	2	6	11.22	398.28	403.38	406.96	411.86	633.34	776.1	780.46			
431 KBOS ALTIMETER 30.02	3	4	330.42	410.04	414.28	420.22	735.56	742					
431 KBOS ATIS GOLF CURRENT	1	4	166.4	490.04	493.38	499.04	642.32	657.26					
431 CONTACT BOS TOWER 132.22	2	2	15.36	649.86	659.56	660.38							
431 TAXI TO TERMINAL B VIA K.B.A-2	2	3	19.6	939.1	951.84	955.42	962.86						
431 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	11.4	993.26	997.72	999.46	1009.98	1020.62					
432 CROSS SCUPP AT 11,000 FT 230 KIAS	0	0		0									
432 EXPECT TAXI TO TERMINAL B VIA E	4	5	17.74	359	362.02	365.14	370	375.02	378.46				
432 KBOS ALTIMETER 30.02	1	2	7.58	410.04	412.38	422.9							
432 EXPECT TAXI TO TERMINAL B VIA K.B.E	8	10	10.26	430.54	698.3	725.38	786.18	845.46	906.26	965.54	434.1	438.96	445.7
432 KBOS ATIS GOLF CURRENT	1	3	8.08	490.04	495	503.46	546.02						
432 CONTACT BOS TOWER 132.22	1	2	11.54	593.48	596.94	609.86							
432 TAXI TO TERMINAL B VIA K.B.A-2	2	4	10.86	859.04	865.04	868.1	874.34	906.26					
432 AMENDED CLEARANCE TAXI TO TERMINAL B VIA K.E-1	2	4	12.8	922.7	926	930.38	939.7	965.54					
471 KBOS ATIS KILO CURRENT	3	3	186.08	30.04	35.36	54.78	213.42						
471 KBOS ALTIMETER 30.04	1	2	9.1	60	66.22	70.48							
471 EXPECT TAXI TO RW 33L VIA A.F.M.C	3	4	141.88	60.02	73.2	79.88	196.58	206.74					
471 CLEARED TO START	1	2	10.26	91.82	99.14	103.52							
471 PUSHBACK AT 2102Z	1	2	17.1	95.06	107.78	117.1							
471 EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	5	6	11.96	120.04	267.24	294.94	354.22	126.92	130.04	136.86			

471	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	8	13	9.18	465.9	483.06	535.1	594.38	655.18	714.46	775.26	468.1	471.38	480.38
471	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	9	9	11.36	778.3	821.2	834.54	895.34	954.62	1015.4	1074.7	1135.5	780.78	783.56
471	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	5	11.46	1043.9	1046.54	1061.02	1074.7	1079.82	1135.5				
472	KBOS ATIS KILO CURRENT	2	4	8.22	30.04	31.26	36.52	43.74	71.1					
472	KBOS ALTIMETER 30.04	1	2	37.42	60	93.04	98.86							
472	EXPECT TAXI TO RW 33L VIA A.F.M.C	2	3	50.78	60.02	102.32	107.58	115.18						
472	EXPECT TAXI TO RW 33L VIA A.Q.M.F.H.RW22L.C	4	5	9.66	120.04	392.26	431.34	125.38	127.98	130.92				
472	CLEARED TO START	1	2	9.8	140.78	148.22	151.38							
472	PUSHBACK AT 1509Z	1	1	14.52	144.82	154.38								
472	TAXI TO RW 33L VIA A.C HOLD SHORT RW 27	2	4	8.16	475.28	477.78	481.02	487.58	490.62					
472	AMENDED CLEARANCE TAXI TO RW 33L VIA M.E.P.D.C HOLD SHORT RW 27	8	10	40.08	782.92	880.46	910.14	970.94	1030.22	1091	1150.3	805.16	814.34	826.54
472	AMENDED CLEARANCE TAXI TO RW 33L VIA C HOLD SHORT RW 33L	1	5	20.7	1075.1	1076.82	1084.6	1090.82	1100.14	1150.3				

Case	Avg Response Time
21x	12.31428571
25x	25.80625
32x	17.97142857
36x	16.38375
43x	46.09571429
47x	37.9825

Type	Avg Response Time
Info	41.58083333
Freq	18.76666667
PB/St	20.74333333
Exp	24.48833333
Taxi	11.01333333
Amd	15.12333333

Type	Avg FD Error
PBase	0.762049333
RBase	0.2463935
PRecv	1.844667167
RRecv	0.228487833
POth	0.831230083
ROth	0.345969
Phi	2.190920375
Rhi	0.404144875
Pmed	0.548764
Rmed	0.246524125
Plo	0.462198125
Rlo	0.2244455

Alt	Ave "Exp Taxi" Response by Altitude
16k	12.43
14k	15.25
10k	32.45
8k	13.60
7k	14.91
5k	10.74
Grnd	32.41

Alt	Ave "Info" Response Time by Altitude
High	10.17
Med	16.79
Low	60.69
Freq	18.77

Appendix L: Data Comm Response Time Distributions

Unlike Appendix K, Appendix L contains analysis results that removed Data Comm response times caused by the pilot forgetting to acknowledge a message after reading it and briefing it to the other crew member. A very conservative limit of 120 seconds was used, which resulted in 39 of the 1056 Data Comm Uplink response times being removed (approximately 4%). Of these, 34 were responded to at a time greater than 120 seconds and 5 messages were not responded to at all. The break-down of these messages (i.e., those that are not included in the statistical analysis of this Appendix) was as follows:

Data Comm message type	**Percent**	**Response > 2 min**	**N**
Pushback and Start:	4%	5 of 132	127
Expected Taxi-Out (ground):	6%	8 of 132	124
Taxi-Out (ground):	0%	0 of 66	66
Amended Taxi-In & Out (ground):	4%	8 of 198	190
Expected Taxi-In (airborne):	2%	3 of 132	129
Taxi-In:	0%	0 of 66	66
Frequency change:	2%	1 of 66	65
ATIS (ground and airborne):	6%	8 of 132	124
Altimeter (ground and airborne):	5%	6 of 132	126
TOTAL		**39 of 1056**	**1017**

NOTE 1: Of the eight Amended Taxi uplink messages that were removed from data analysis in this Appendix, four were Amended Taxi-Out messages that were responded to but at a time greater than 120 seconds, and four were Amended Taxi-In messages not responded to at all. It is postulated the four Amended Taxi-In messages not responded may be due to the scenario being terminated prior to the flight crew responding to the message.

NOTE 2: The fifth Data Comm message not responded to at all was an altimeter change uplink message during an arrival. It is not known why the crew did not respond.

The root cause for pilots not acknowledging or not acknowledging the Uplink messages in a timely fashion was likely the intentional selection of the FANS-1/A interface, creating a non-optimized Data Comm solution for terminal area operations.

Figure 47 to 54 present the response time distribution by Data Comm message type. The following labels define terms unique to these data.

Skewness: values closer to 0 indicate symmetric data, negative values indicate left skew, positive values indicate right skew. Skew direction is the direction of the tail. Right skew means tail points right as we see below.

Kurtosis: values closer to 0 indicate normally peaked data (relative to all data points), negative values indicate a distribution that is flatter than normal, positive values indicate a distribution that is sharper than normal.

The following graphs show response time distribution by Data Comm message type.

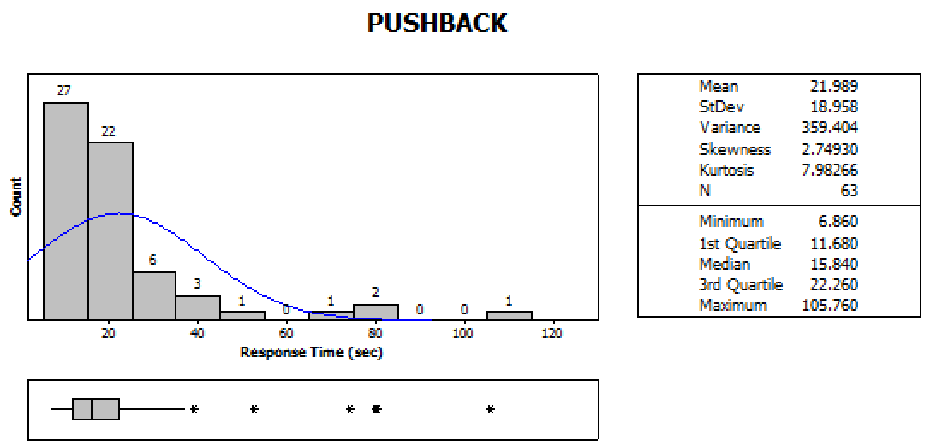


Figure 50. Response time to Pushback message

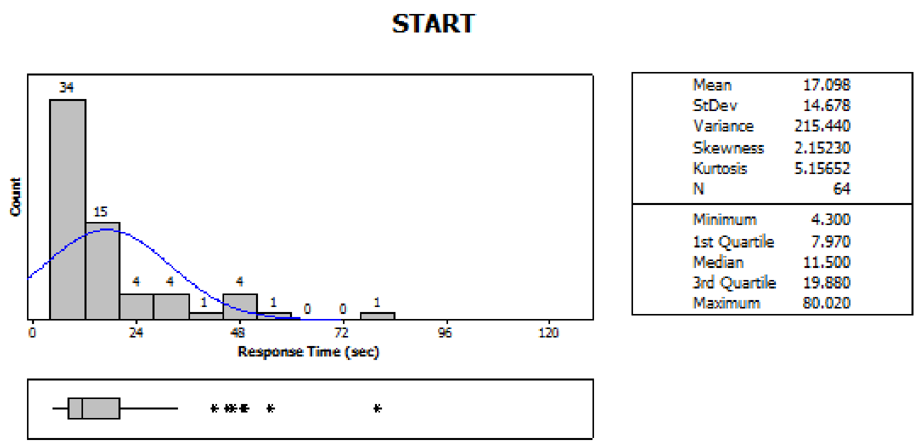


Figure 51. Response time to Start message

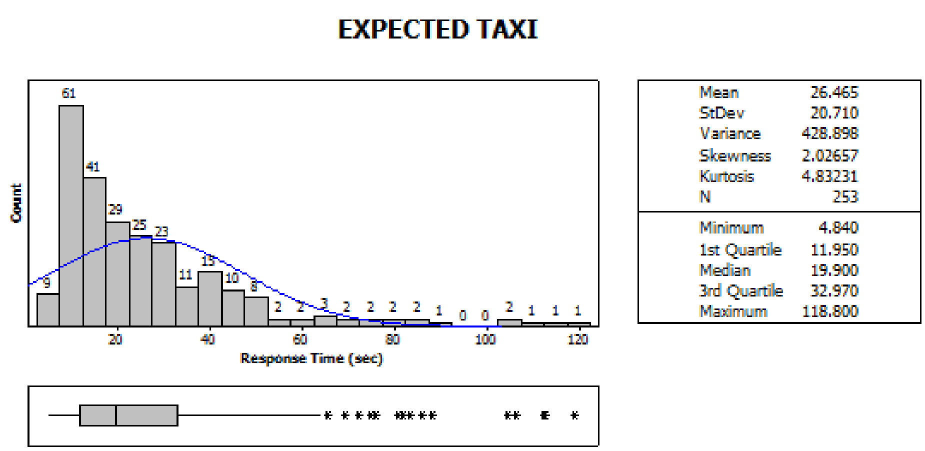


Figure 52. Response time to Expected Taxi message

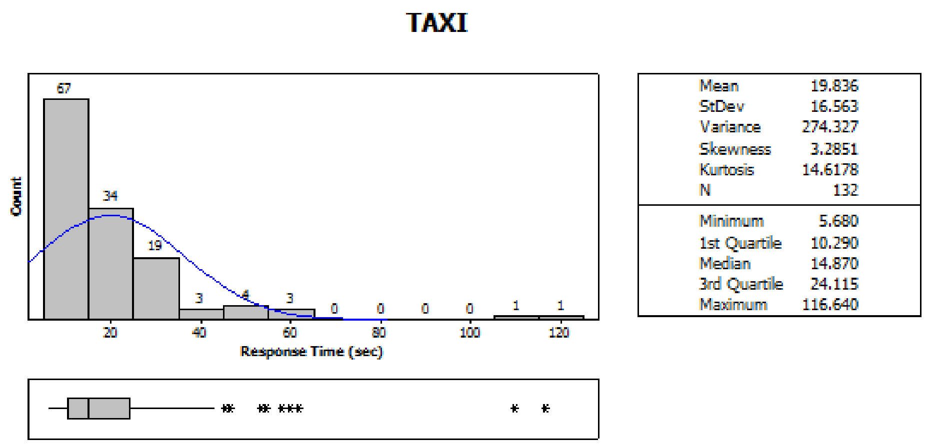


Figure 53. Response time to Taxi message

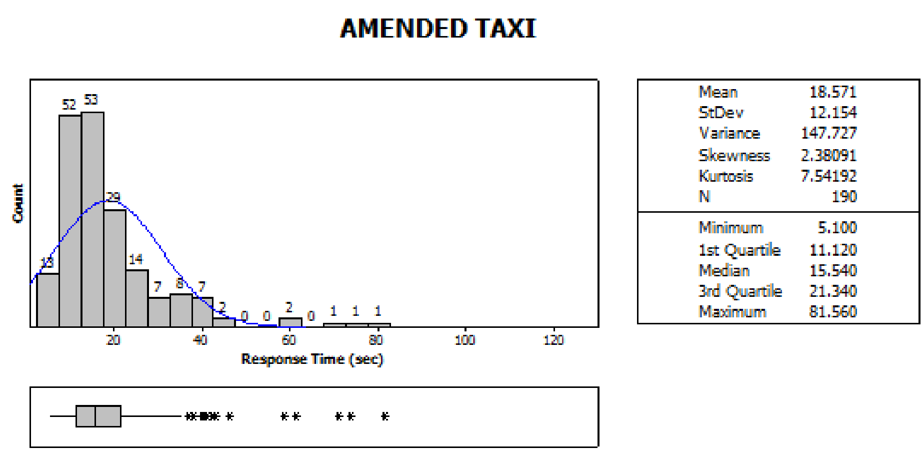


Figure 54. Response time to Amended Taxi

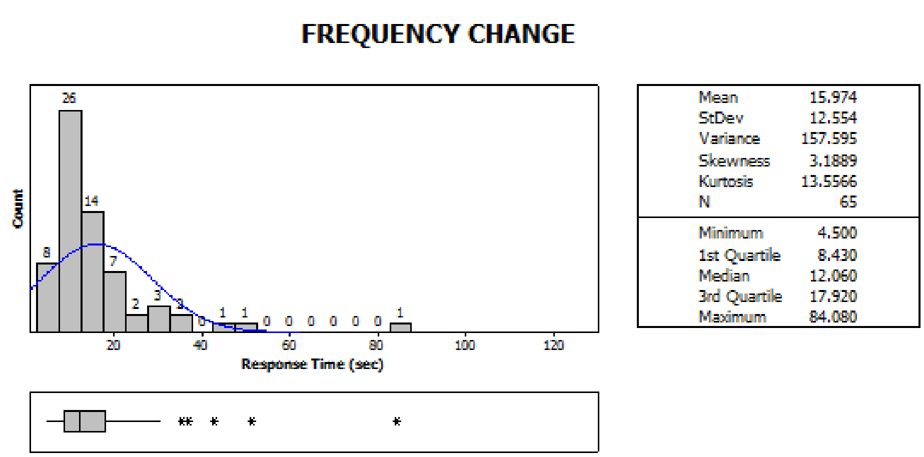


Figure 55. Response time to Frequency change message

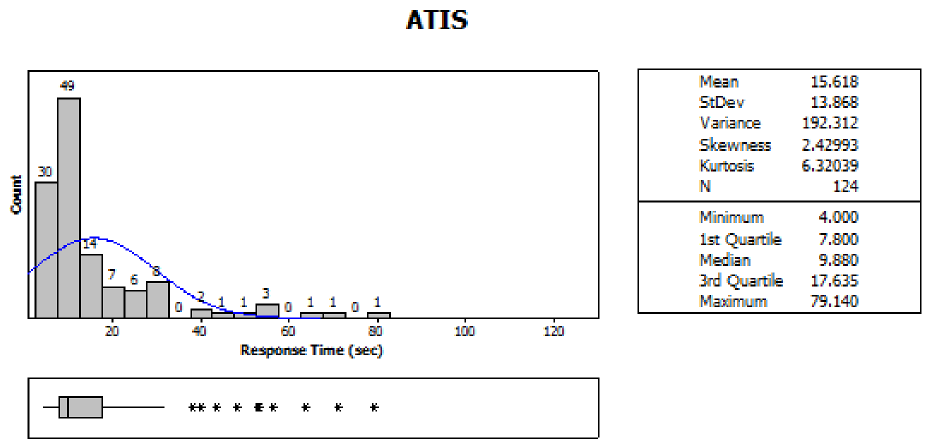


Figure 56. Response time to ATIS message

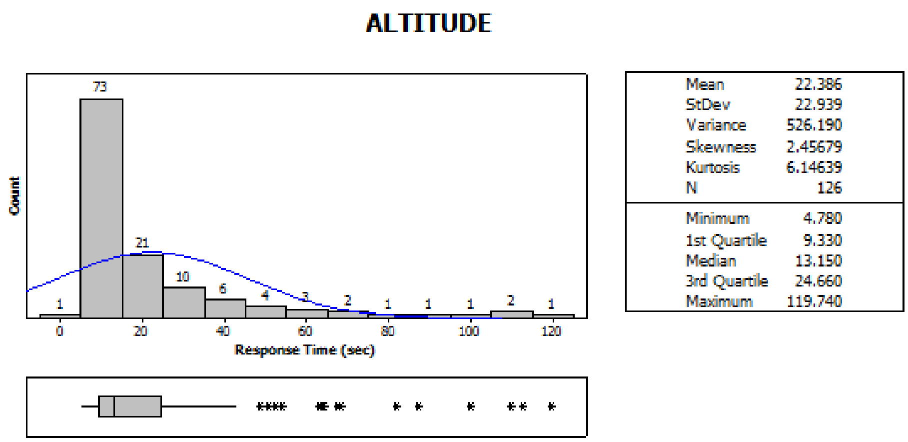


Figure 57. Response time to Altimeter change

Appendix M: Data Comm Response Time Tables for SC-214

In Table 42 through Table 45 of this appendix the flight crew response time to Data Comm uplink messages are tabulated according to the classification table used by the RTCA SC-214 work group. This was a special request by the FAA after the experiment had been conducted, but prior to publishing the original NASA report. Data analysis of pilot response time indicated that there was no statistically significant difference in message response time across display methodology ($F=1.51$, $p=0.222$); however, there was a statistically significant difference in message response across message type ($F=13.06$, $p<0.001$). (Data used by FAA and RTCA to inform development of Reference 33.)

Table 42. Data Comm response time for all display conditions

	Service	ACM	DTAXI					ACL
Domain		VCM	RP					FI
		Frequency	Route planning					Flight Info
TMA		RCP 102 UM117 **(7) Freq**		RCP 181 UMDT05 **(5) Expect Taxi-In**				RCP 102 UM212 & UM213 **(8) ATIS &**
	average	15.97		20.70				14.97
	95%	35.46		40.78				31.98
	99.90%	51.24		63.00				48.76
Airport			RCP 47 UMDT01 & UMDT02 **(1)**	RCP 181 UMDT05 **(2) Expect Taxi-Out**	RCP 181 UMDT10 **(3) Taxi-Out**	RCP 181 UMDT15 **(4) Amend Taxi-**	RCP 181 UMDT10 **(6) Taxi-In**	RCP 102 UM212 & UM213 **(9) ATIS &**
	average		19.52	33.12	14.58	18.57	25.09	23.03
	95%		46.54	72.44	23.94	38.00	58.12	53.86
	99.90%		55.16	104.62	33.68	46.10	61.68	87.34

Table 43. Data Comm response time by Paper display condition

	Service	ACM	DTAXI					ACL
Domain		VCM	RP					FI
		Frequency	Route planning					Flight Info
TMA		RCP 102 UM117 **(7) Freq**		RCP 181 UMDT05 **(5) Expect Taxi-In**				RCP 102 UM212 & UM213 **(8) ATIS & Alt**
	average	16.18		17.61				19.32
	95%	29.00		32.66				31.98
	99.90%	29.00		32.66				68.46
Airport			RCP 47 UMDT01 & UMDT02 **(1)**	RCP 181 UMDT05 **(2) Expect Taxi-Out**	RCP 181 UMDT10 **(3) Taxi-Out**	RCP 181 UMDT15 **(4) Amend Taxi-**	RCP 181 UMDT10 **(6) Taxi-In**	RCP 102 UM212 & UM213 **(9) ATIS & Alt**
	average		20.72	37.82	13.89	17.61	25.37	19.44
	95%		46.54	49.08	20.92	29.86	43.00	50.77
	99.90%		52.50	112.52	20.92	46.10	61.68	71.06

Table 44. Data Comm response time by MMD display condition

	Service	ACM	DTAXI					ACL
Domain		VCM Frequency	RP Route planning					FI Flight Info
TMA		RCP 102 UM117 **(7) Freq**		RCP 181 UMDT05 **(5) Expect Taxi-In**				RCP 102 UM212 & UM213 **(8) ATIS & Alt**
	average	18.23		23.50				10.91
	95%	36.78		40.78				18.02
	99.90%	51.24		53.24				20.16
Airport	Table G-2 timers	100s	45s/100s/180s Note 11					
			RCP 47 UMDT01 & UMDT02 **(1)**	RCP 181 UMDT05 **(2) Expect Taxi-Out**	RCP 181 UMDT10 **(3) Taxi-Out**	RCP 181 UMDT15 **(4) Amend Taxi-**	RCP 181 UMDT10 **(6) Taxi-In**	RCP 102 UM212 & UM213 **(9) ATIS & Alt**
	average		17.36	28.23	16.48	17.59	22.77	21.40
	95%		35.52	59.70	23.86	37.00	33.48	52.68
	99.90%		42.20	83.28	33.68	43.12	116.64	63.80

NOTE: Row shaded in blue is from original FAA table, and is not pertinent to this experiment.

Table 45. Data Comm response time by MMD+Route display condition

	Service	ACM	DTAXI					ACL
Domain		VCM Frequency	RP Route planning					FI Flight Info
TMA		RCP 102 UM117 **(7) Freq**		RCP 181 UMDT05 **(5) Expect Taxi-In**				RCP 102 UM212 & UM213 **(8) ATIS & Alt**
	average	13.39		18.96				14.86
	95%	19.22		38.82				30.00
	99.90%	19.22		58.18				36.00
Airport			RCP 47 UMDT01 & UMDT02 **(1)**	RCP 181 UMDT05 **(2) Expect Taxi-Out**	RCP 181 UMDT10 **(3) Taxi-Out**	RCP 181 UMDT15 **(4) Amend Taxi-**	RCP 181 UMDT10 **(6) Taxi-In**	RCP 102 UM212 & UM213 **(9) ATIS & Alt**
	average		20.54	33.80	13.36	20.44	27.14	28.82
	95%		55.16	65.72	19.06	40.08	46.48	62.90
	99.90%		80.02	88.14	30.70	58.52	60.00	119.74

Appendix N: Oculometer Results

N.1 General Information

N.1.1 Interpreting the ANOVA

Analysis of Variance (ANOVA) identifies statistically significant variance across groups of data. ANOVA performs a statistical test to determine if the means of various groups are equal, generalizing a two-sample t-test to two or more groups. An adjusted *P*-value of 0.05 or less is considered significant, and is indicated by yellow highlighting in this appendix. The ANOVAs shown below are General Linear Model (GLM) ANOVAs, with the model: Condition, PF-PM, and Condition*PF-PM (interaction term). This produces results indicating variance across Condition, variance across PF-PM, and the interaction term of Condition crossed with PF-PM. The interaction term identifies if there is variance between the variance across condition within the PF group and the variance across condition in the PM group (i.e., if the observed variance under varying conditions followed a similar trend for each pilot or not).

N.1.2 Interpreting the Graphical Outputs

<u>(1) Residual Plots</u>

a) Histogram of residuals. An exploratory tool to show general characteristics of the data, including:

- Typical values, spread or variation, and shape
- Unusual values in the data

Long tails in the plot may indicate skewness in the data. If one or two bars are far from the others, those points may be outliers. Because the appearance of the histogram changes depending on the number of intervals used to group the data, use the normal probability plot and goodness-of-fit tests to assess the normality of the residuals.

b) Normal plot of residuals. The points in this plot should generally form a straight line if the residuals are normally distributed. If the points on the plot depart from a straight line, the normality assumption may be invalid. If your data have fewer than 50 observations, the plot may display curvature in the tails even if the residuals are normally distributed. As the number of observations decreases, the probability plot may show substantial variation and nonlinearity even if the residuals are normally distributed.

c) Residuals versus fits. This plot should show a random pattern of residuals on both sides of 0. If a point lies far from the majority of points, it may be an outlier. Also, there should not be any recognizable patterns in the residual plot. The following may indicate error that is not random:

- a series of increasing or decreasing points
- a predominance of positive residuals, or a predominance of negative residuals
- patterns, such as increasing residuals with increasing fits

d) Residuals versus order. This is a plot of all residuals in the order that the data was collected and can be used to find non-random error, especially of time-related effects. A positive correlation is indicated by a clustering of residuals with the same sign. A negative correlation is indicated by rapid changes in the signs of consecutive residuals. [40]

(2) Main Effects Plot

The main effects plot shows the average value for each main effect of the ANOVA model and draws a connecting line to emphasize the relative comparisons independently for PF /PM and Conditions.

(3) Interaction Plot

The interaction plot shows the average values of the combined effects in the ANOVA model, helping to identify variance across Conditions grouped by PF and PM.

N.2 Arrival: High altitude messages

General Linear Model: Percent head up versus Condition, PF - PM

```
Factor      Type   Levels  Values
Condition   fixed       4  1 Voice/Paper, 2 Data/Paper, 3 Data/MMD, 4
                           Data/MMD+Route
PF - PM     fixed       2  PF, PM


Analysis of Variance for Percent Head Up (High Band), using Adjusted SS for
     Tests

Source               DF   Seq SS   Adj SS  Adj MS     F      P
Condition             3   4070.0   4018.3  1339.4  8.10  0.000
PF - PM               1    392.6    367.7   367.7  2.22  0.138
Condition*PF - PM     3    454.0    454.0   151.3  0.92  0.435
Error               151  24970.4  24970.4   165.4
Total               158  29887.0


S = 12.8595   R-Sq = 16.45%   R-Sq(adj) = 12.58%




Unusual Observations for Percent Head Up (High Band)

Obs  Percent      Fit  SE Fit  Residual     St Resid
 23  59.9911  11.9312  2.8755   48.0599       3.83 R
 50  52.6620  15.7882  2.8755   36.8738       2.94 R
 58  58.5643  23.0469  2.8062   35.5174       2.83 R
 91  48.5083  12.2729  2.8062   36.2354       2.89 R
 92  48.5083  12.2729  2.8062   36.2354       2.89 R
 93  37.1604   5.6591  2.8755   31.5013       2.51 R
112  54.9374  11.2222  2.8755   43.7152       3.49 R

R denotes an observation with a large standardized residual.


Tukey 95.0% Simultaneous Confidence Intervals
```

```
Response Variable Percent Head Up (High Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

Condition           Lower  Center   Upper
2 Data/Paper       -17.23   -9.86  -2.484
3 Data/MMD         -21.45  -13.87  -6.285
4 Data/MMD+Route   -15.26   -7.84  -0.423

Condition           -+---------+---------+---------+-----
2 Data/Paper            (------*-------)
3 Data/MMD          (------*-------)
4 Data/MMD+Route          (------*-------)
                    -+---------+---------+---------+-----
                   -20       -10         0        10


Condition = 2 Data/Paper  subtracted from:

Condition           Lower  Center  Upper   -+---------+---------+---------+-----
3 Data/MMD         -11.59  -4.009  3.572            (-------*-------)
4 Data/MMD+Route    -5.40   2.016  9.434                   (------*------)
                                           -+---------+---------+---------+-----
                                          -20       -10         0        10


Condition = 3 Data/MMD  subtracted from:

Condition           Lower  Center  Upper   -+---------+---------+---------+-----
4 Data/MMD+Route   -1.599   6.025  13.65                       (-------*-------)
                                           -+---------+---------+---------+-----
                                          -20       -10         0        10


Tukey Simultaneous Tests
Response Variable Percent Head Up (High Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

                   Difference       SE of             Adjusted
Condition            of Means  Difference  T-Value     P-Value
2 Data/Paper            -9.86       2.841   -3.469      0.0038
3 Data/MMD             -13.87       2.921   -4.746      0.0000
4 Data/MMD+Route        -7.84       2.858   -2.743      0.0341


Condition = 2 Data/Paper  subtracted from:

                   Difference       SE of             Adjusted
Condition            of Means  Difference  T-Value     P-Value
3 Data/MMD             -4.009       2.921   -1.372      0.5186
4 Data/MMD+Route        2.016       2.858    0.705      0.8949


Condition = 3 Data/MMD  subtracted from:

                   Difference       SE of             Adjusted
Condition            of Means  Difference  T-Value     P-Value
4 Data/MMD+Route        6.025       2.938    2.051      0.1743
```

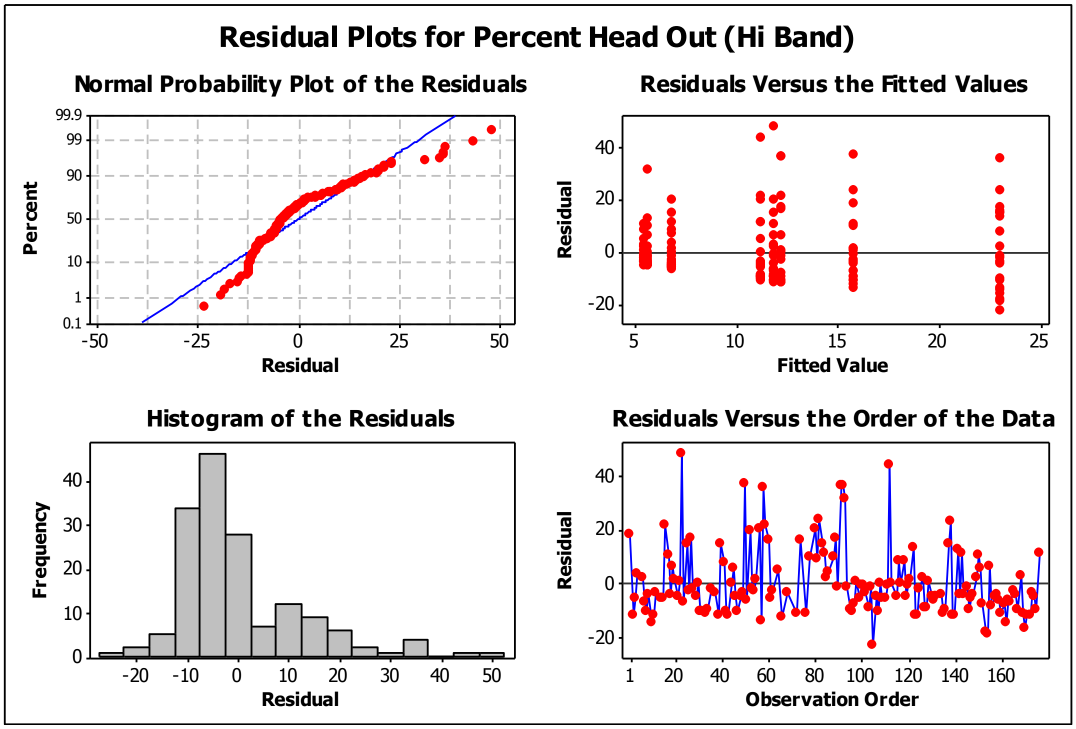


Figure 58. Residual plots for percent head up (16 – 14,000 feet MSL)

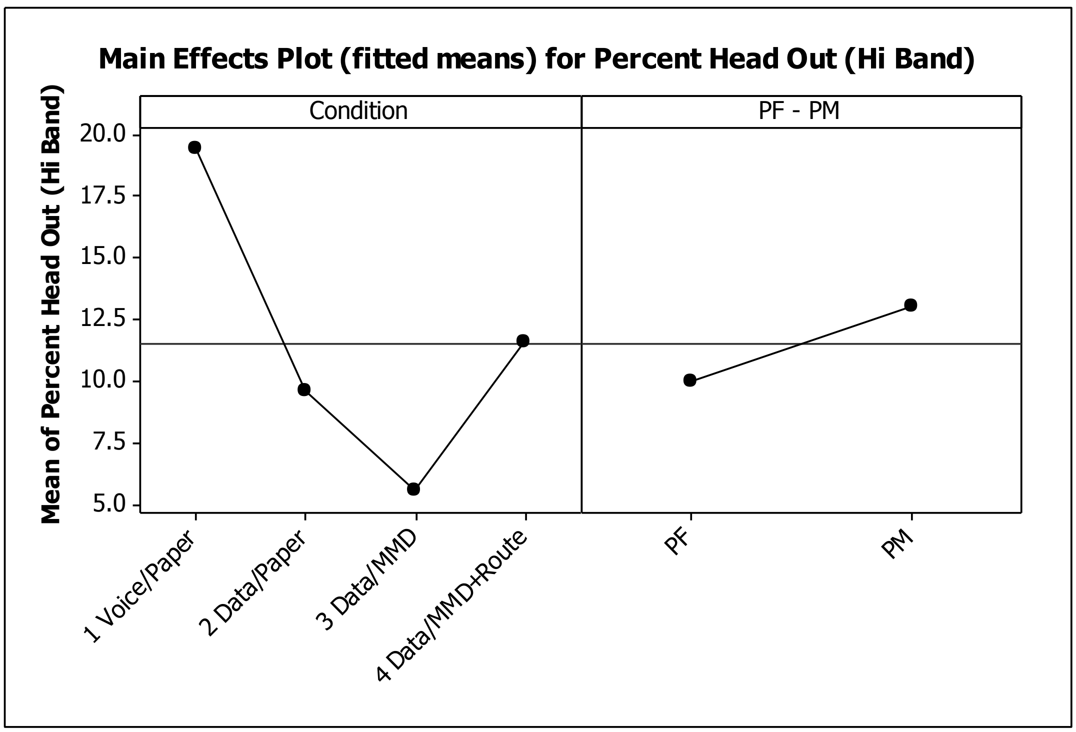


Figure 59. Main effects plot (fitted means) for percent head up (16 – 14,000 feet MSL)

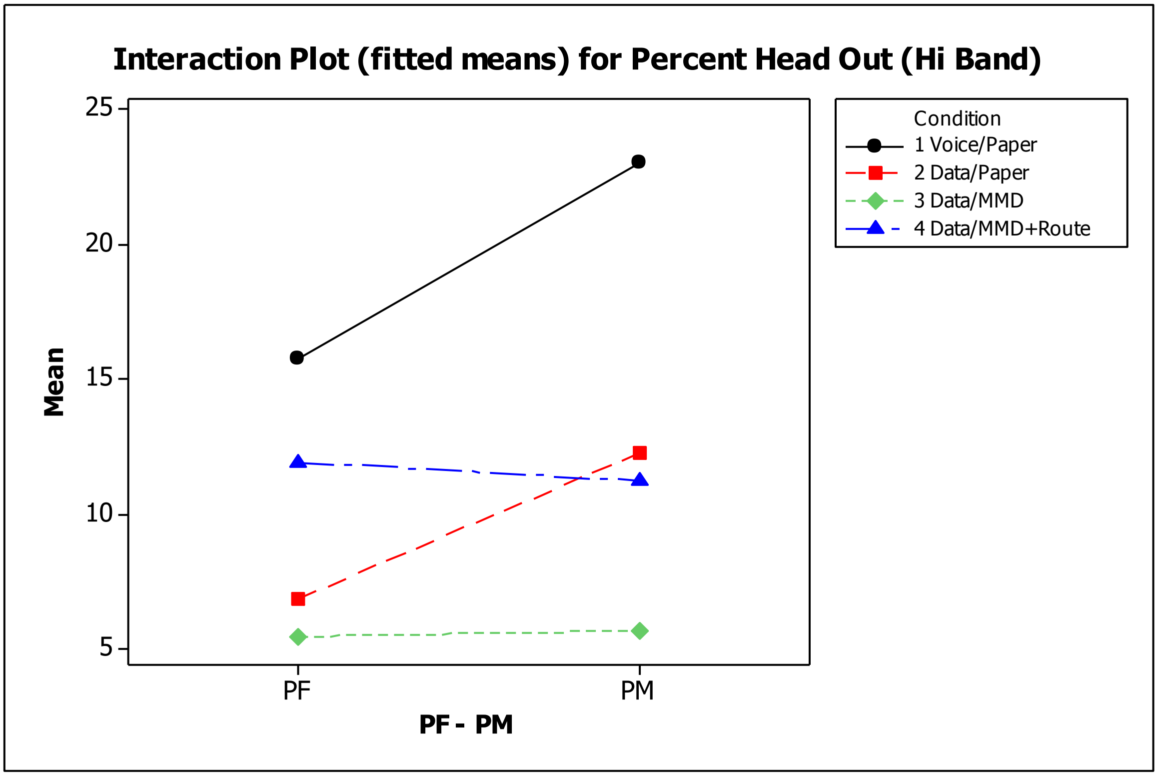


Figure 60. Interaction plot (fitted means) for percent head up (16 – 14,000 feet MSL)

N.3 Arrival: Medium altitude messages

General Linear Model: Percent Head Up versus Condition, PF - PM

```
Factor      Type   Levels  Values
Condition   fixed       4  1 Voice/Paper, 2 Data/Paper, 3 Data/MMD, 4
                           Data/MMD+Route
PF - PM     fixed       2  PF, PM


Analysis of Variance for Percent Head Up (Med Band), using Adjusted SS for
     Tests

Source                DF   Seq SS   Adj SS   Adj MS     F      P
Condition              3   2600.4   2579.9    860.0  3.96  0.009
PF - PM                1    481.4    486.0    486.0  2.24  0.137
Condition*PF - PM      3    578.8    578.8    192.9  0.89  0.449
Error                151  32826.6  32826.6    217.4
Total                158  36487.2


S = 14.7443   R-Sq = 10.03%   R-Sq(adj) = 5.86%


Unusual Observations for Percent Head Up (Med Band)

Obs  Percent      Fit  SE Fit  Residual  St Resid
 58  56.6589  22.8489  3.2175   33.8100      2.35 R
```

80	62.8501	12.4426	3.2969	50.4075	3.51	R
89	61.0188	22.8489	3.2175	38.1699	2.65	R
113	57.8865	16.1795	3.2969	41.7070	2.90	R
116	45.9061	13.7628	3.2969	32.1433	2.24	R
124	41.2925	11.0928	3.2175	30.1997	2.10	R
141	60.6329	12.1394	3.2969	48.4935	3.37	R
145	61.7805	16.1795	3.2969	45.6010	3.17	R
146	50.8180	16.1795	3.2969	34.6385	2.41	R
147	43.0785	13.7628	3.2969	29.3157	2.04	R
149	56.2240	8.5562	3.5760	47.6678	3.33	R

R denotes an observation with a large standardized residual.

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Med Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

Condition           Lower  Center   Upper
2 Data/Paper       -15.54   -7.09   1.367
3 Data/MMD         -17.86   -9.17  -0.474
4 Data/MMD+Route   -18.79  -10.29  -1.782

Condition           ---+---------+---------+---------+---
2 Data/Paper            (---------*----------)
3 Data/MMD            (----------*---------)
4 Data/MMD+Route     (---------*----------)
                    ---+---------+---------+---------+---
                  -16.0      -8.0       0.0       8.0


Condition = 2 Data/Paper  subtracted from:

Condition           Lower  Center  Upper   ---+---------+---------+---------+---
3 Data/MMD         -10.77  -2.080  6.612            (---------*----------)
4 Data/MMD+Route   -11.71  -3.201  5.304          (----------*----------)
                                           ---+---------+---------+---------+---
                                         -16.0      -8.0       0.0       8.0


Condition = 3 Data/MMD  subtracted from:

Condition           Lower  Center  Upper   ---+---------+---------+---------+---
4 Data/MMD+Route   -9.863  -1.121  7.622             (----------*----------)
                                           ---+---------+---------+---------+---
                                         -16.0      -8.0       0.0       8.0
```

Tukey Simultaneous Tests
Response Variable Percent Head Up (Med Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2 Data/Paper	-7.09	3.257	-2.175	0.1348
3 Data/MMD	-9.17	3.350	-2.737	0.0347
4 Data/MMD+Route	-10.29	3.277	-3.139	0.0109

Condition = 2 Data/Paper subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3 Data/MMD	-2.080	3.350	-0.6210	0.9252
4 Data/MMD+Route	-3.201	3.277	-0.9766	0.7630

Condition = 3 Data/MMD subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4 Data/MMD+Route	-1.121	3.369	-0.3326	0.9873

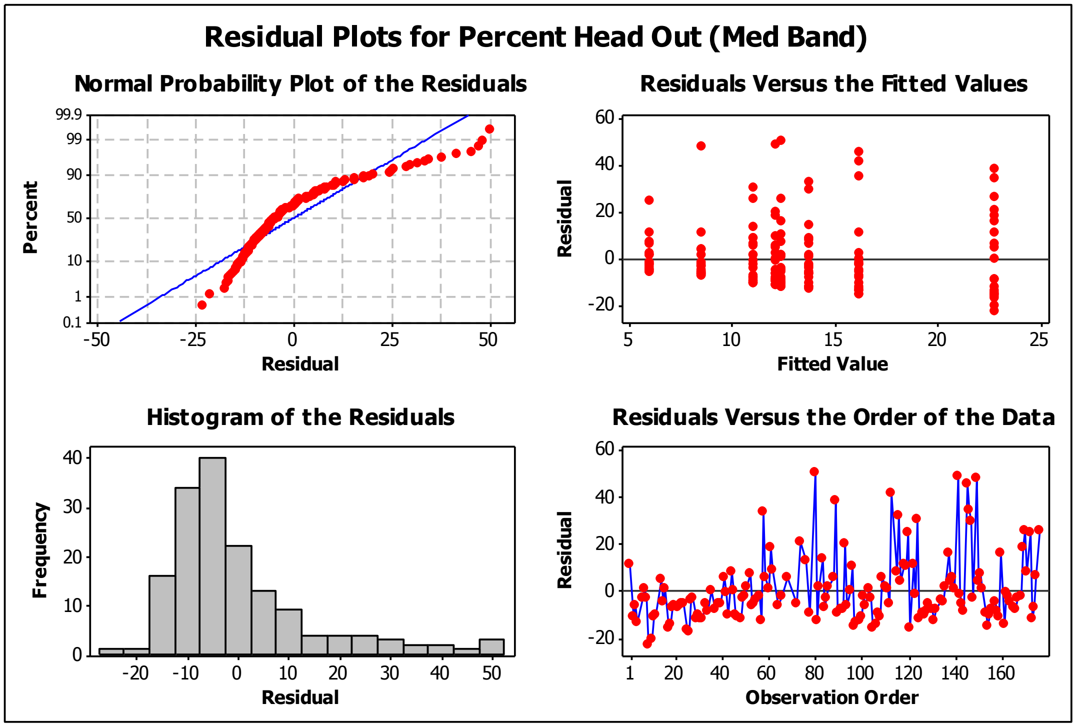


Figure 61. Residual plots for percent head up (10 – 8,000 feet MSL)

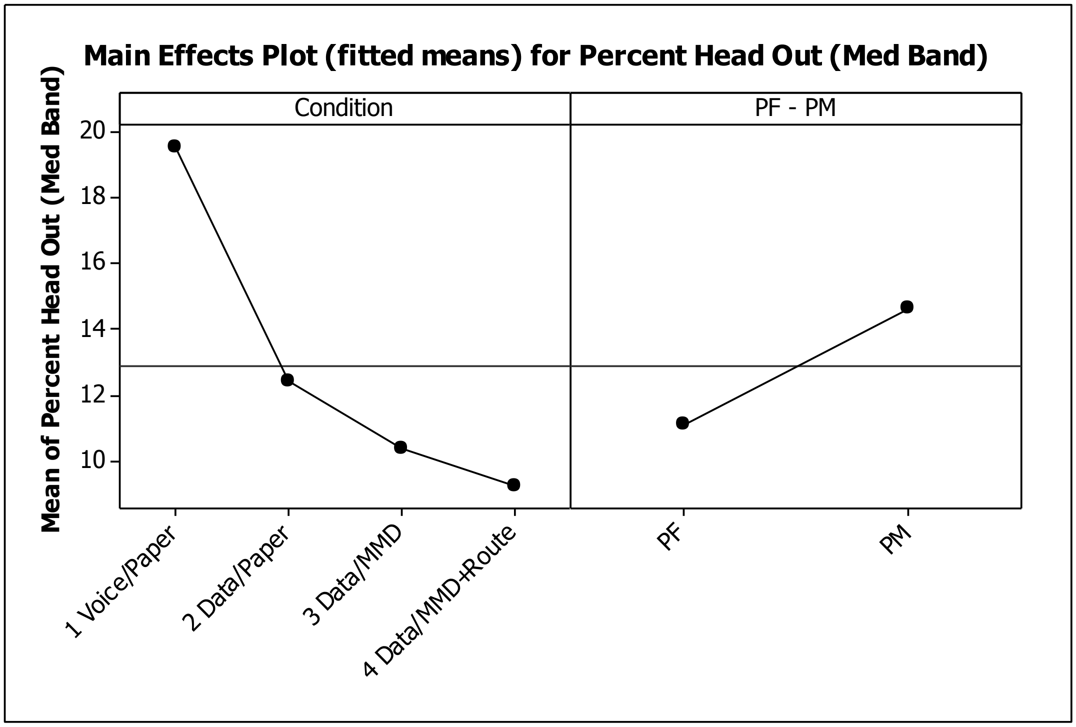


Figure 62. Main effects plot (fitted means) for percent head up (10 – 8,000 feet MSL)

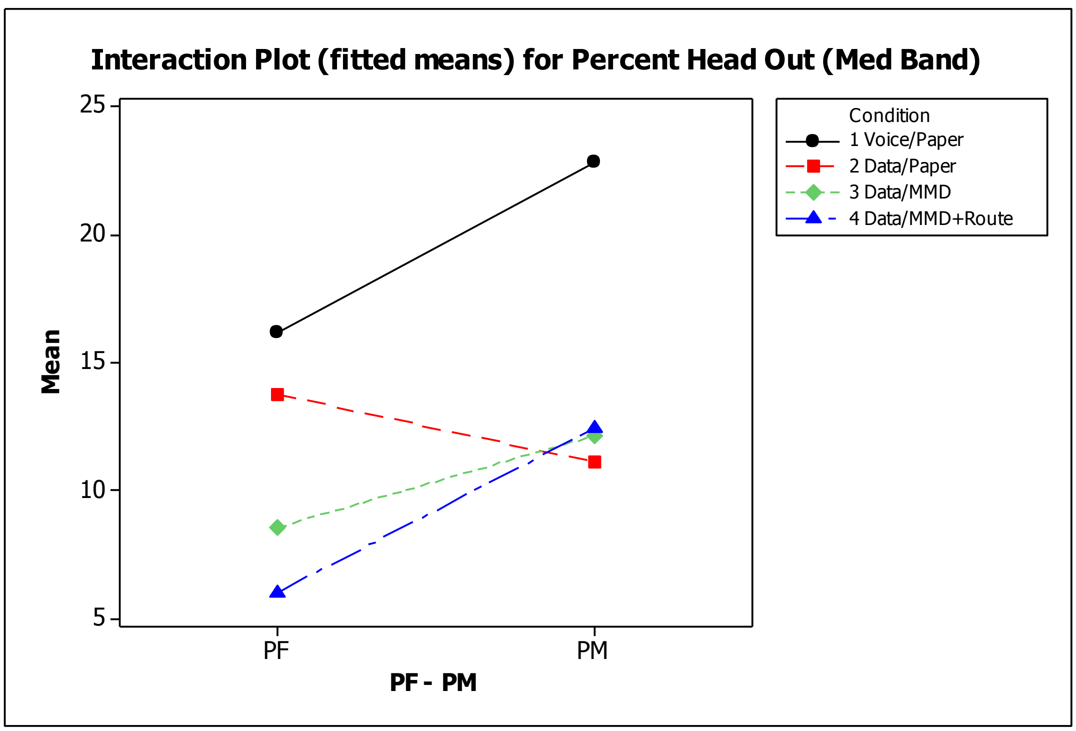


Figure 63. Interaction plot (fitted means) for percent head up (10 – 8,000 feet MSL)

N.4 Arrival: Low altitude messages

General Linear Model: Percent Head Up versus Condition, PF - PM

```
Factor     Type   Levels  Values
Condition  fixed       4  1 Voice/Paper, 2 Data/Paper, 3 Data/MMD, 4
                          Data/MMD+Route
PF - PM    fixed       2  PF, PM
```

```
Analysis of Variance for Percent Head Up (Low Band), using Adjusted SS for
     Tests
```

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	3	2326.5	2288.0	762.7	4.46	0.005
PF - PM	1	702.9	699.6	699.6	4.09	0.045
Condition*PF - PM	3	476.8	476.8	158.9	0.93	0.428
Error	151	25805.2	25805.2	170.9		
Total	158	29311.5				

```
S = 13.0727   R-Sq = 11.96%   R-Sq(adj) = 7.88%
```

```
Unusual Observations for Percent Head Up (Low Band)
```

Obs	Percent	Fit	SE Fit	Residual	St Resid
1	43.8347	10.5682	2.9231	33.2665	2.61 R
55	38.9768	13.4396	2.9231	25.5372	2.00 R
58	50.9821	19.3774	2.8527	31.6047	2.48 R
61	47.8629	16.1893	2.9231	31.6736	2.49 R
95	47.8224	12.6623	2.9231	35.1601	2.76 R
118	39.7289	11.0439	3.1706	28.6850	2.26 R
138	61.4298	19.3774	2.8527	42.0524	3.30 R
150	58.0565	11.0439	3.1706	47.0126	3.71 R
172	43.4291	7.1894	2.8527	36.2397	2.84 R
174	49.3665	16.1893	2.9231	33.1772	2.60 R
175	44.7406	12.6623	2.9231	32.0783	2.52 R

```
R denotes an observation with a large standardized residual.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Low Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

Condition           Lower  Center   Upper  -------+---------+---------+---------
2 Data/Paper       -17.10  -9.601  -2.106  (------*-------)
3 Data/MMD          -9.06  -1.356   6.351          (-------*------)
4 Data/MMD+Route    -9.46  -1.922   5.619          (------*-------)
                                           -------+---------+---------+---------
                                                -10         0        10

Condition = 2 Data/Paper  subtracted from:

Condition           Lower  Center  Upper  -------+---------+---------+---------
3 Data/MMD         0.5381   8.245  15.95                    (------*-------)
4 Data/MMD+Route   0.1389   7.679  15.22                   (-------*------)
                                          -------+---------+---------+---------
                                               -10         0        10

Condition = 3 Data/MMD  subtracted from:
```

```
Condition            Lower    Center  Upper  -------+---------+---------+---------
4 Data/MMD+Route    -8.317  -0.5657  7.186           (------*-------)
                                             -------+---------+---------+---------
                                                  -10         0        10


Tukey Simultaneous Tests
Response Variable Percent Head Up (Low Band)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

                     Difference       SE of           Adjusted
Condition              of Means  Difference  T-Value   P-Value
2 Data/Paper             -9.601       2.888   -3.324    0.0061
3 Data/MMD               -1.356       2.970   -0.457    0.9682
4 Data/MMD+Route         -1.922       2.906   -0.661    0.9114

Condition = 2 Data/Paper  subtracted from:

                     Difference       SE of           Adjusted
Condition              of Means  Difference  T-Value   P-Value
3 Data/MMD                8.245       2.970    2.776    0.0312
4 Data/MMD+Route          7.679       2.906    2.643    0.0445


Condition = 3 Data/MMD  subtracted from:

                     Difference       SE of           Adjusted
Condition              of Means  Difference  T-Value   P-Value
4 Data/MMD+Route        -0.5657       2.987  -0.1894    0.9976
```

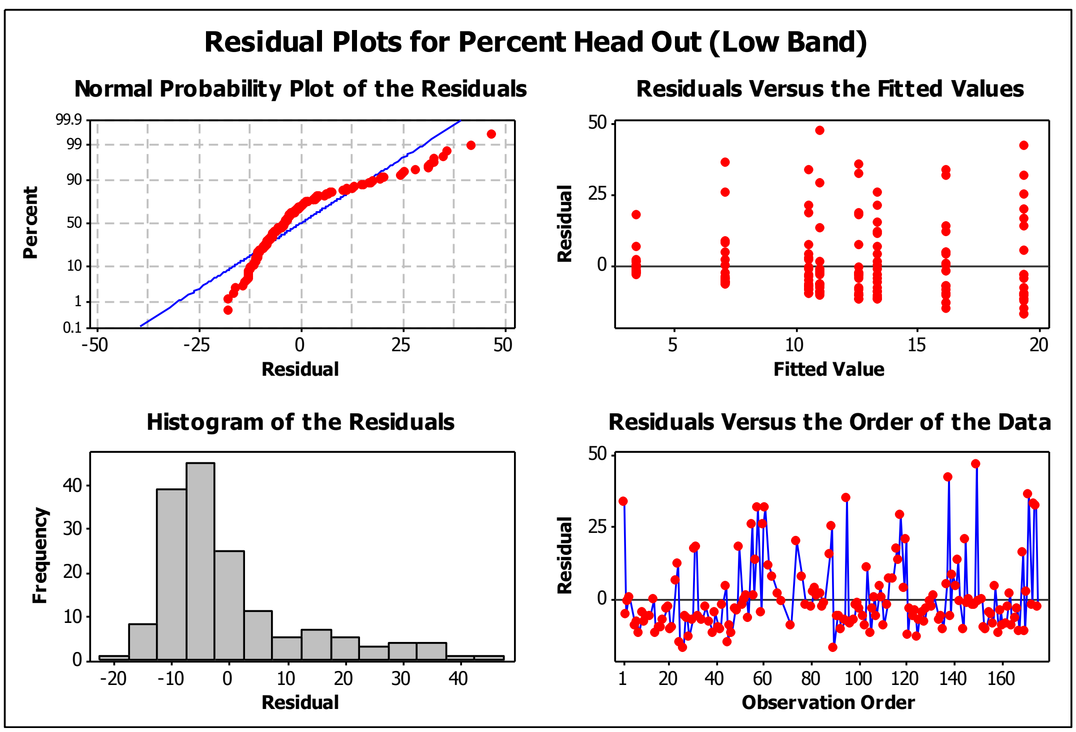


Figure 64. Residual plots for percent head up (7 – 5,000 feet MSL)

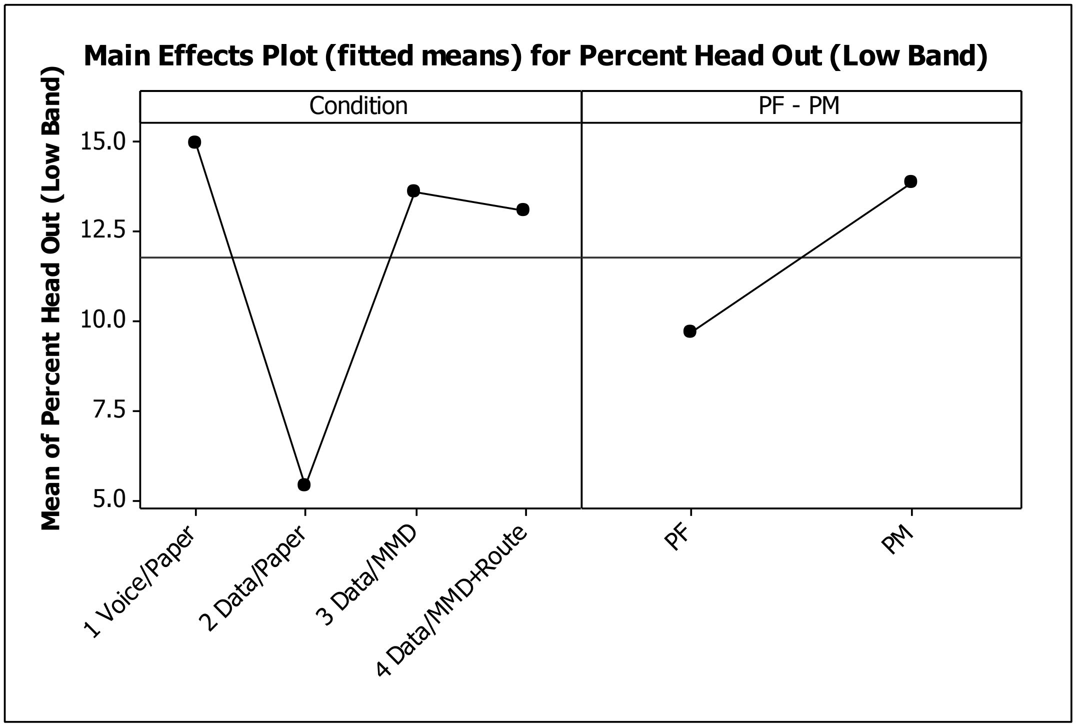


Figure 65. Main effects plot (fitted means) for percent head up (7 – 5,000 feet MSL)

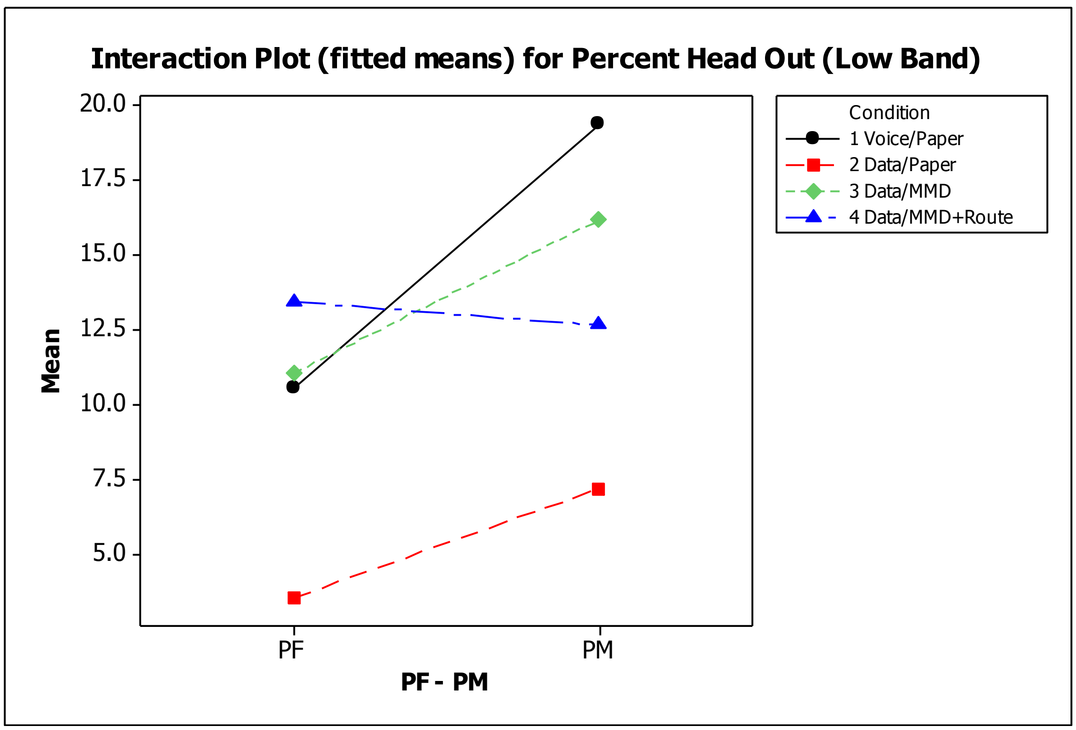


Figure 66. Interaction plot (fitted means) for percent head up (7 – 5,000 feet MSL)

N.5 Arrival: Taxi operations

Taxi operations during an arrival scenario began once the aircraft slowed below 80 KIAS during landing roll-out for oculometer data analysis.

General Linear Model: Percent head up versus Condition, PF - PM

Factor	Type	Levels	Values
Condition	fixed	4	1 Voice/Paper, 2 Data/Paper, 3 Data/MMD, 4 Data/MMD+Route
PF - PM	fixed	2	PF, PM

Analysis of Variance for Percent Head Up (below 80 knots), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	3	3155.6	2997.1	999.0	4.47	0.005
PF - PM	1	19915.9	20100.5	20100.5	89.89	0.000
Condition*PF - PM	3	2790.3	2790.3	930.1	4.16	0.007
Error	147	32869.5	32869.5	223.6		
Total	154	58731.3				

S = 14.9533   R-Sq = 44.03%   R-Sq(adj) = 41.37%

Unusual Observations for Percent Head Up (below 80 knots)

Obs	Percent	Fit	SE Fit	Residual	St Resid	
17	83.4763	53.7174	3.3437	29.7589	2.04	R
34	23.8551	53.7174	3.3437	-29.8623	-2.05	R
50	89.2779	53.7174	3.3437	35.5605	2.44	R
72	87.2655	53.8645	3.4305	33.4010	2.29	R
99	28.0447	59.5175	3.3437	-31.4728	-2.16	R
135	22.5296	53.8645	3.4305	-31.3349	-2.15	R
145	17.6622	53.7174	3.3437	-36.0552	-2.47	R
154	13.0155	44.2720	3.2631	-31.2565	-2.14	R
176	53.6511	22.4910	3.4305	31.1601	2.14	R

R denotes an observation with a large standardized residual.

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (below 80 knots)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

Condition           Lower   Center   Upper  ----+---------+---------+---------+--
2 Data/Paper       -12.02    -3.42   5.174           (----------*---------)
3 Data/MMD         -18.31    -9.33  -0.359   (----------*-----------)
4 Data/MMD+Route   -19.58   -10.82  -2.054  (---------*----------)
                                            ----+---------+---------+---------+--
                                            -16.0      -8.0       0.0       8.0


Condition = 2 Data/Paper  subtracted from:

Condition           Lower   Center  Upper  ----+---------+---------+---------+--
3 Data/MMD         -14.88   -5.910  3.063       (-----------*----------)
4 Data/MMD+Route   -16.16   -7.394  1.369      (----------*----------)
```

```
                                     ----+---------+---------+---------+--
                                     -16.0      -8.0       0.0       8.0


Condition = 3 Data/MMD  subtracted from:

Condition           Lower  Center  Upper  ----+---------+---------+---------+--
4 Data/MMD+Route  -10.62  -1.484  7.650             (----------*-----------)
                                          ----+---------+---------+---------+--
                                          -16.0      -8.0       0.0       8.0
```

```
Tukey Simultaneous Tests
Response Variable Percent Head Up (below 80 knots)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:
```

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2 Data/Paper	-3.42	3.304	-1.036	0.7286
3 Data/MMD	-9.33	3.449	-2.706	0.0378
4 Data/MMD+Route	-10.82	3.368	-3.212	0.0087

Condition = 2 Data/Paper subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3 Data/MMD	-5.910	3.449	-1.714	0.3202
4 Data/MMD+Route	-7.394	3.368	-2.196	0.1292

Condition = 3 Data/MMD subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4 Data/MMD+Route	-1.484	3.510	-0.4228	0.9745

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (below 80 knots)
All Pairwise Comparisons among Levels of PF - PM
PF - PM = PF  subtracted from:

PF
-
PM   Lower  Center   Upper  -----+---------+---------+---------+-
PM  -27.61  -22.85  -18.09  (-----*-----)
                            -----+---------+---------+---------+-
                             -24.0     -16.0      -8.0       0.0
```

```
Tukey Simultaneous Tests
Response Variable Percent Head Up (below 80 knots)
All Pairwise Comparisons among Levels of PF - PM
PF - PM = PF  subtracted from:
```

PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
PM	-22.85	2.410	-9.481	0.0000

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (below 80 knots)
```

```
All Pairwise Comparisons among Levels of Condition*PF - PM
Condition = 1 Voice/Paper
PF - PM = PF  subtracted from:

                  PF
                  -
Condition         PM   Lower  Center   Upper
1 Voice/Paper     PM  -23.82   -9.45    4.93
2 Data/Paper      PF   -8.74    5.80   20.34
2 Data/Paper      PM  -36.46  -22.09   -7.72
3 Data/MMD        PF  -18.14   -2.71   12.72
3 Data/MMD        PM  -40.14  -25.40  -10.67
4 Data/MMD+Route  PF  -14.59    0.15   14.88
4 Data/MMD+Route  PM  -45.96  -31.23  -16.49

                  PF
                  -
Condition         PM   -+---------+---------+---------+-----
1 Voice/Paper     PM              (-----*-----)
2 Data/Paper      PF                     (----*-----)
2 Data/Paper      PM         (-----*-----)
3 Data/MMD        PF                 (-----*-----)
3 Data/MMD        PM        (-----*-----)
4 Data/MMD+Route  PF                  (-----*-----)
4 Data/MMD+Route  PM      (-----*----)
                       -+---------+---------+---------+-----
                      -50       -25         0        25


Condition = 1 Voice/Paper
PF - PM = PM  subtracted from:

                  PF
                  -
Condition         PM   Lower  Center   Upper
2 Data/Paper      PF    0.87   15.25  29.616
2 Data/Paper      PM  -26.84  -12.65   1.549
3 Data/MMD        PF   -8.53    6.74  21.999
3 Data/MMD        PM  -30.52  -15.96  -1.394
4 Data/MMD+Route  PF   -4.97    9.59  24.156
4 Data/MMD+Route  PM  -36.34  -21.78  -7.218

                  PF
                  -
Condition         PM   -+---------+---------+---------+-----
2 Data/Paper      PF                        (-----*-----)
2 Data/Paper      PM             (-----*-----)
3 Data/MMD        PF                     (-----*-----)
3 Data/MMD        PM            (-----*----)
4 Data/MMD+Route  PF                      (-----*-----)
4 Data/MMD+Route  PM         (-----*-----)
                       -+---------+---------+---------+-----
                      -50       -25         0        25


Condition = 2 Data/Paper
PF - PM = PF  subtracted from:

                  PF
                  -
Condition         PM   Lower  Center   Upper
2 Data/Paper      PM  -42.26  -27.89  -13.52
3 Data/MMD        PF  -23.94   -8.51    6.92
```

```
3 Data/MMD        PM  -45.94  -31.20  -16.47
4 Data/MMD+Route  PF  -20.39   -5.65    9.08
4 Data/MMD+Route  PM  -51.76  -37.03  -22.29

                  PF
                  -
Condition         PM   -+---------+---------+---------+-----
2 Data/Paper      PM       (-----*-----)
3 Data/MMD        PF              (------*-----)
3 Data/MMD        PM      (-----*----)
4 Data/MMD+Route  PF                (-----*-----)
4 Data/MMD+Route  PM   (-----*-----)
                       -+---------+---------+---------+-----
                      -50       -25         0        25


Condition = 2 Data/Paper
PF - PM = PM  subtracted from:

                  PF
                  -
Condition         PM   Lower  Center   Upper
3 Data/MMD        PF    4.12  19.381  34.645
3 Data/MMD        PM  -17.87  -3.312  11.252
4 Data/MMD+Route  PF    7.67  22.238  36.801
4 Data/MMD+Route  PM  -23.70  -9.136   5.427

                  PF
                  -
Condition         PM   -+---------+---------+---------+-----
3 Data/MMD        PF                        (-----*-----)
3 Data/MMD        PM               (-----*-----)
4 Data/MMD+Route  PF                         (-----*-----)
4 Data/MMD+Route  PM             (----*-----)
                       -+---------+---------+---------+-----
                      -50       -25         0        25


Condition = 3 Data/MMD
PF - PM = PF  subtracted from:

                  PF
                  -
Condition         PM   Lower  Center   Upper
3 Data/MMD        PM  -38.30  -22.69   -7.09
4 Data/MMD+Route  PF  -12.75    2.86   18.46
4 Data/MMD+Route  PM  -44.12  -28.52  -12.91

                  PF
                  -
Condition         PM   -+---------+---------+---------+-----
3 Data/MMD        PM         (-----*-----)
4 Data/MMD+Route  PF                   (-----*-----)
4 Data/MMD+Route  PM      (------*-----)
                       -+---------+---------+---------+-----
                      -50       -25         0        25


Condition = 3 Data/MMD
PF - PM = PM  subtracted from:

                  PF
                  -
```

Condition	PF - PM	Lower	Center	Upper
4 Data/MMD+Route	PF	10.63	25.549	40.472
4 Data/MMD+Route	PM	-20.75	-5.824	9.099

```
                   PF
                   -
Condition          PM   -+---------+---------+---------+-----
4 Data/MMD+Route   PF                             (-----*-----)
4 Data/MMD+Route   PM               (-----*-----)
                        -+---------+---------+---------+-----
                       -50       -25         0        25
```

Condition = 4 Data/MMD+Route
PF - PM = PF subtracted from:

Condition	PF - PM	Lower	Center	Upper
4 Data/MMD+Route	PM	-46.30	-31.37	-16.45

```
                   PF
                   -
Condition          PM   -+---------+---------+---------+-----
4 Data/MMD+Route   PM     (-----*-----)
                        -+---------+---------+---------+-----
                       -50       -25         0        25
```

Tukey Simultaneous Tests - (Including Interaction Comparison)
Response Variable Percent Head Up (below 80 knots)
All Pairwise Comparisons among Levels of Condition*PF - PM
Condition = 1 Voice/Paper
PF - PM = PF subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
1 Voice/Paper	PM	-9.45	4.672	-2.022	0.4710
2 Data/Paper	PF	5.80	4.729	1.227	0.9228
2 Data/Paper	PM	-22.09	4.672	-4.728	0.0002
3 Data/MMD	PF	-2.71	5.016	-0.540	0.9994
3 Data/MMD	PM	-25.40	4.790	-5.303	0.0000
4 Data/MMD+Route	PF	0.15	4.790	0.031	1.0000
4 Data/MMD+Route	PM	-31.23	4.790	-6.518	0.0000

Condition = 1 Voice/Paper
PF - PM = PM subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2 Data/Paper	PF	15.25	4.672	3.263	0.0291
2 Data/Paper	PM	-12.65	4.615	-2.740	0.1190
3 Data/MMD	PF	6.74	4.962	1.358	0.8747
3 Data/MMD	PM	-15.96	4.735	-3.370	0.0210
4 Data/MMD+Route	PF	9.59	4.735	2.026	0.4681
4 Data/MMD+Route	PM	-21.78	4.735	-4.600	0.0003

Condition = 2 Data/Paper
PF - PM = PF subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2 Data/Paper	PM	-27.89	4.672	-5.970	0.0000
3 Data/MMD	PF	-8.51	5.016	-1.697	0.6895
3 Data/MMD	PM	-31.20	4.790	-6.513	0.0000
4 Data/MMD+Route	PF	-5.65	4.790	-1.180	0.9364
4 Data/MMD+Route	PM	-37.03	4.790	-7.729	0.0000

Condition = 2 Data/Paper
PF - PM = PM subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3 Data/MMD	PF	19.381	4.962	3.906	0.0035
3 Data/MMD	PM	-3.312	4.735	-0.699	0.9969
4 Data/MMD+Route	PF	22.238	4.735	4.697	0.0002
4 Data/MMD+Route	PM	-9.136	4.735	-1.930	0.5330

Condition = 3 Data/MMD
PF - PM = PF subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3 Data/MMD	PM	-22.69	5.074	-4.473	0.0004
4 Data/MMD+Route	PF	2.86	5.074	0.563	0.9992
4 Data/MMD+Route	PM	-28.52	5.074	-5.620	0.0000

Condition = 3 Data/MMD
PF - PM = PM subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4 Data/MMD+Route	PF	25.549	4.852	5.266	0.0000
4 Data/MMD+Route	PM	-5.824	4.852	-1.200	0.9307

Condition = 4 Data/MMD+Route
PF - PM = PF subtracted from:

Condition	PF - PM	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4 Data/MMD+Route	PM	-31.37	4.852	-6.467	0.0000

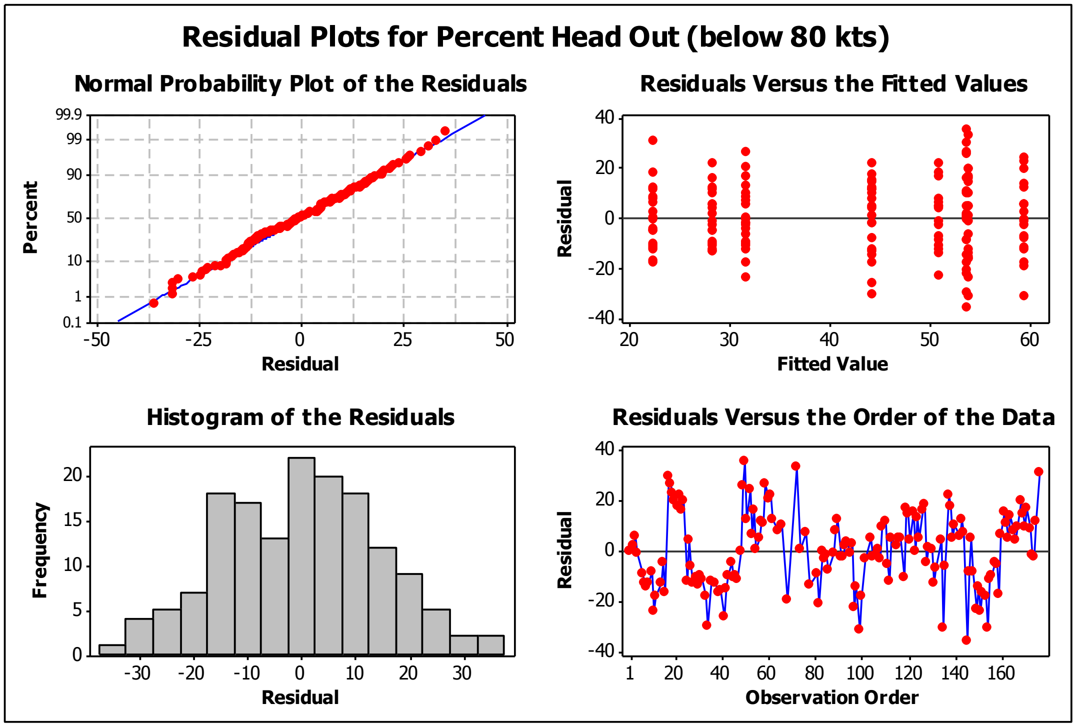


Figure 67. Residual plots for percent head up (below 80 knots)

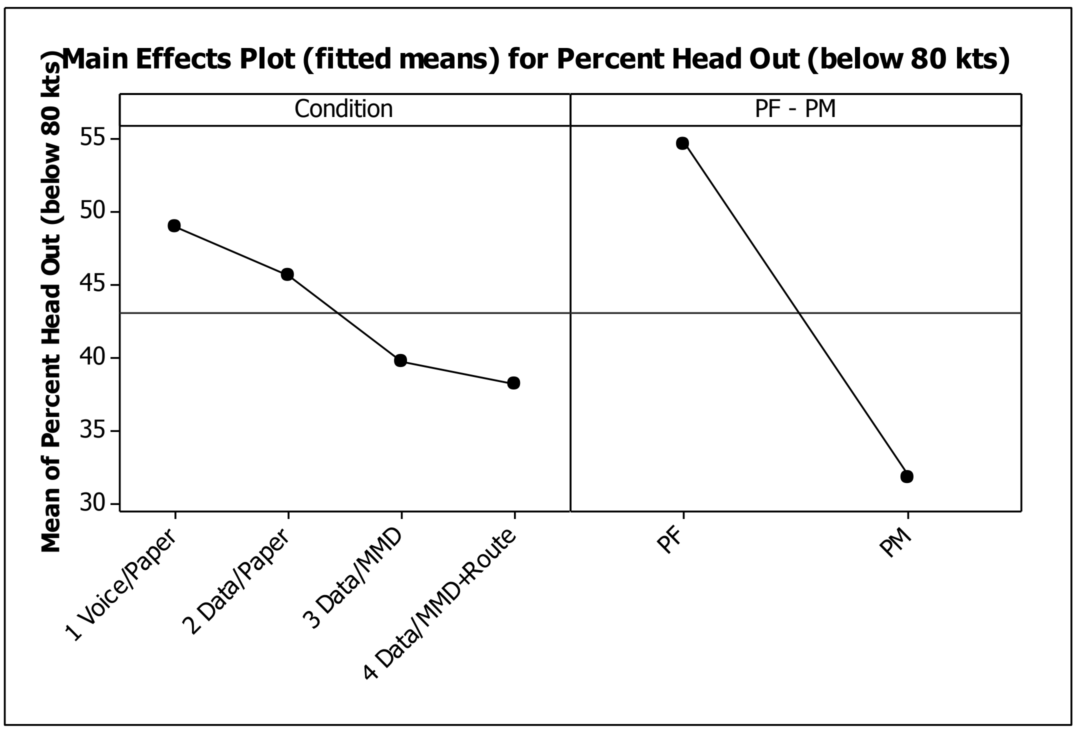


Figure 68. Main effects plot (fitted means) for percent head up (below 80 knots)

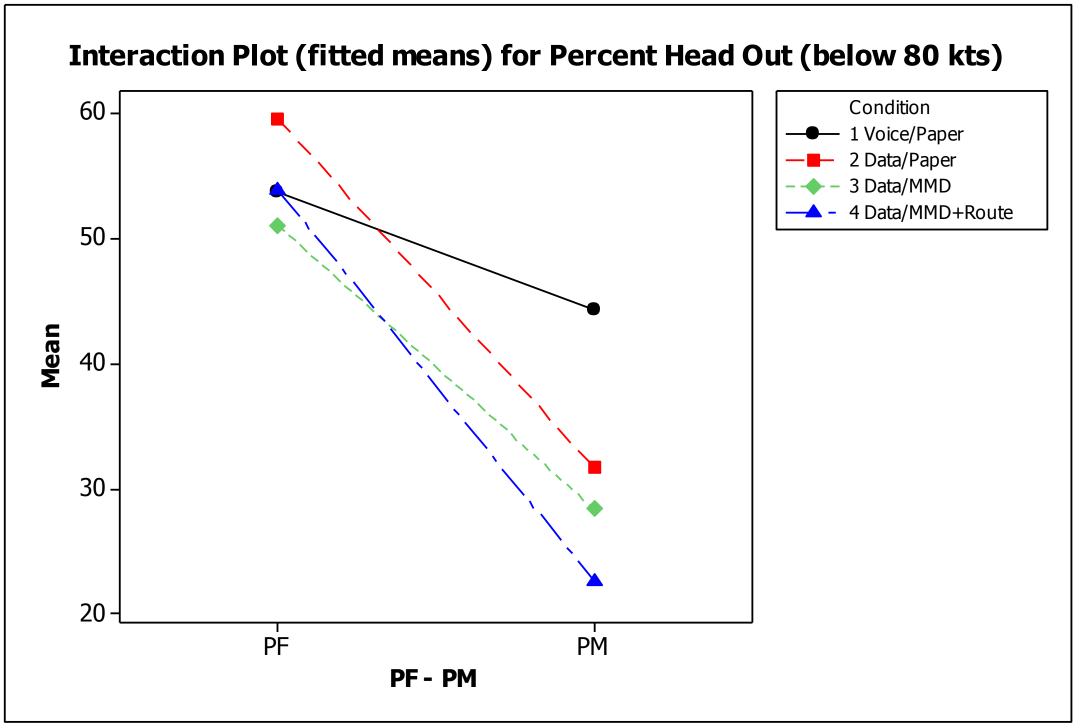


Figure 69. Interaction plot (fitted means) for percent head up (below 80 knots)

N.6 Departure: entire scenario

General Linear Model: Percent head up versus Condition, PF - PM

```
Factor     Type   Levels  Values
Condition  fixed       4  1 Voice/Paper, 2 Data/Paper, 3 Data/MMD, 4
                          Data/MMD+Route
PF - PM    fixed       2  PF, PM


Analysis of Variance for Percent Head Up (Entire Run), using Adjusted SS for
     Tests

Source              DF   Seq SS   Adj SS   Adj MS       F      P
Condition            3   2732.9   2659.7    886.6   11.08  0.000
PF - PM              1  15732.4  15660.6  15660.6  195.70  0.000
Condition*PF - PM    3    488.0    488.0    162.7    2.03  0.112
Error              152  12163.2  12163.2     80.0
Total              159  31116.5


S = 8.94547   R-Sq = 60.91%   R-Sq(adj) = 59.11%


Unusual Observations for Percent Head Up (Entire Run)

Obs  Percent      Fit  SE Fit  Residual  St Resid
  2  53.2186  71.2814  2.0003  -18.0628     -2.07 R
 10  31.9115  53.1752  1.9521  -21.2637     -2.44 R
 11  24.9345  42.5773  1.9521  -17.6428     -2.02 R
 50  90.6775  71.2814  2.0003   19.3961      2.22 R
 58  71.6278  53.1752  1.9521   18.4526      2.11 R
 60  61.6453  42.5773  1.9521   19.0680      2.18 R
124  22.7567  42.5773  1.9521  -19.8206     -2.27 R
153  28.0458  53.1752  1.9521  -25.1294     -2.88 R
170  71.3411  53.1752  1.9521   18.1659      2.08 R
174  60.4640  39.8905  2.0003   20.5735      2.36 R
176  66.1148  46.7586  2.0522   19.3562      2.22 R

R denotes an observation with a large standardized residual.


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper  subtracted from:

Condition           Lower  Center   Upper
2 Data/Paper       -12.99   -7.89  -2.795
3 Data/MMD         -16.21  -10.98  -5.747
4 Data/MMD+Route   -13.21   -8.01  -2.821

Condition           ---+---------+---------+---------+---
2 Data/Paper            (-------*------)
3 Data/MMD          (------*-------)
4 Data/MMD+Route         (-------*------)
                    ---+---------+---------+---------+---
                  -14.0      -7.0       0.0       7.0


Condition = 2 Data/Paper  subtracted from:
```

```
Condition           Lower  Center  Upper   ---+---------+---------+---------+---
3 Data/MMD         -8.288  -3.087  2.114             (-------*------)
4 Data/MMD+Route   -5.285  -0.122  5.041                 (-------*------)
                                           ---+---------+---------+---------+---
                                          -14.0      -7.0       0.0       7.0
```

Condition = 3 Data/MMD subtracted from:

```
Condition           Lower  Center  Upper   ---+---------+---------+---------+---
4 Data/MMD+Route   -2.331   2.965  8.261                      (------*-------)
                                           ---+---------+---------+---------+---
                                          -14.0      -7.0       0.0       7.0
```

Tukey Simultaneous Tests
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Condition
Condition = 1 Voice/Paper subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2 Data/Paper	-7.89	1.964	-4.018	0.0005
3 Data/MMD	-10.98	2.016	-5.446	0.0000
4 Data/MMD+Route	-8.01	2.002	-4.004	0.0006

Condition = 2 Data/Paper subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3 Data/MMD	-3.087	2.004	-1.540	0.4162
4 Data/MMD+Route	-0.122	1.990	-0.061	0.9999

Condition = 3 Data/MMD subtracted from:

Condition	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4 Data/MMD+Route	2.965	2.041	1.453	0.4688

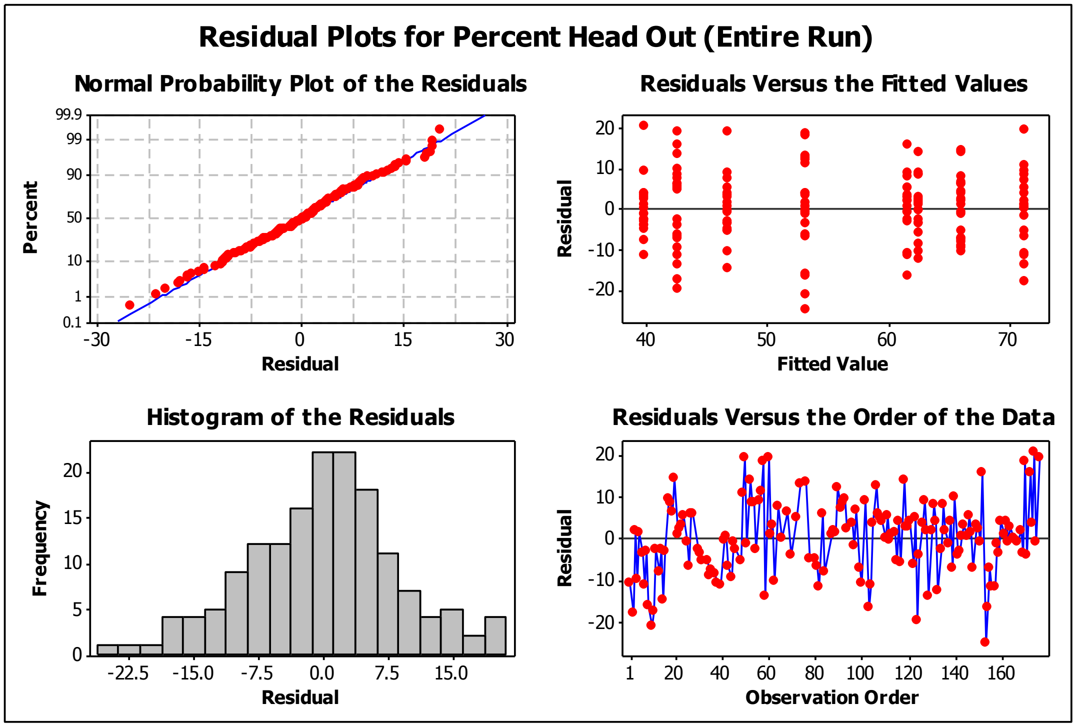


Figure 70. Residual plots for percent head up (entire run)

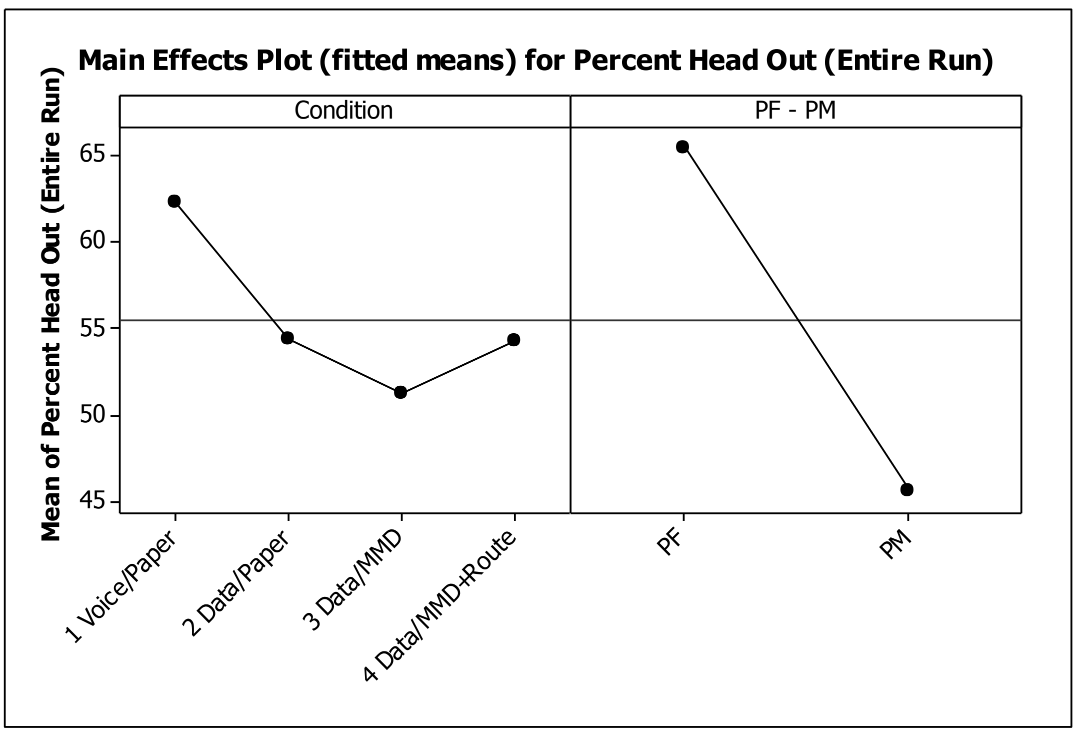


Figure 71. Main effects plot (fitted means) for percent head up (entire run)

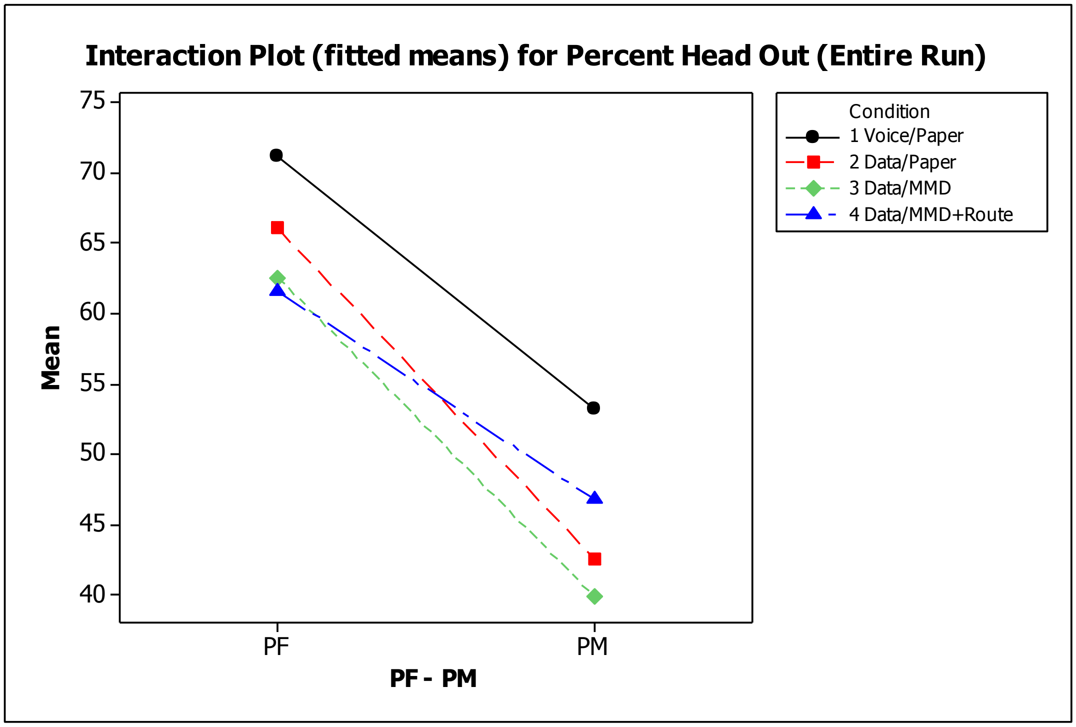


Figure 72. Interaction plot (fitted means) for percent head up (entire run)

N.7 Arrival versus Departure ANOVA

General Linear Model: Percent head up versus PF - PM, Phase, Condition

```
Factor      Type   Levels  Values
PF - PM     fixed       2  PF, PM
Phase       fixed       2  Arr, Dep
Condition   fixed       4  1Voice/Paper, 2Data/Paper, 4DCom/MMD, 4DCom/Rte


Analysis of Variance for Percent Head Up (Entire Run), using Adjusted SS for
     Tests

Source              DF    Seq SS    Adj SS    Adj MS       F      P
PF - PM              1   36887.0   36472.4   36472.4  213.77  0.000
Phase                1   10259.1   11372.9   11372.9   66.66  0.000
Condition            3    6543.2    6127.7    2042.6   11.97  0.000
PF - PM*Phase        1     218.1     244.9     244.9    1.44  0.232
PF - PM*Condition    3    1611.4    1615.7     538.6    3.16  0.025
Phase*Condition      3     684.7     684.7     228.2    1.34  0.262
Error              320   54596.3   54596.3     170.6
Total              332  110799.9


S = 13.0619   R-Sq = 50.73%   R-Sq(adj) = 48.88%


Unusual Observations for Percent Head Up (Entire Run)

Obs  Percent      Fit  SE Fit  Residual  St Resid
```

```
 63  11.5143  58.9509  2.3223  -47.4366     -3.69 R
 99  14.2824  58.9509  2.3223  -44.6685     -3.48 R
162   4.0331  39.1154  2.2540  -35.0823     -2.73 R
181  28.0458  56.1312  2.5765  -28.0854     -2.19 R
208  83.4763  56.8212  2.6254   26.6551      2.08 R
218  23.8551  56.8212  2.6254  -32.9661     -2.58 R
227  89.2779  56.8212  2.6254   32.4567      2.54 R
242  87.2655  50.5721  2.6908   36.6934      2.87 R
253  31.0100  56.8212  2.6254  -25.8112     -2.02 R
255  28.0447  59.2803  2.6228  -31.2356     -2.44 R
277  22.5296  50.5721  2.6908  -28.0425     -2.19 R
280  17.6622  56.8212  2.6254  -39.1590     -3.06 R
327  58.1727  31.8527  2.5742   26.3200      2.06 R
380  13.0155  41.3160  2.5765  -28.3005     -2.21 R
395  53.6511  25.7834  2.6908   27.8677      2.18 R

R denotes an observation with a large standardized residual.


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of PF - PM
PF - PM = PF  subtracted from:

PF
-
PM   Lower  Center   Upper  ----+---------+---------+---------+--
PM  -23.85  -21.02  -18.20  (---*---)
                            ----+---------+---------+---------+--
                            -21.0     -14.0      -7.0       0.0


Tukey Simultaneous Tests
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of PF - PM
PF - PM = PF  subtracted from:

PF
-   Difference       SE of           Adjusted
PM    of Means  Difference  T-Value   P-Value
PM      -21.02       1.438   -14.62    0.0000


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Phase
Phase = Arr  subtracted from:

Phase  Lower  Center  Upper  ----+---------+---------+---------+--
Dep    8.948   11.79  14.63  (-----------------*----------------)
                             ----+---------+---------+---------+--
                               9.6      11.2      12.8      14.4


Tukey Simultaneous Tests
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Phase
Phase = Arr  subtracted from:

       Difference       SE of           Adjusted
Phase    of Means  Difference  T-Value   P-Value
Dep         11.79       1.444    8.165    0.0000
```

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Condition
Condition = 1Voice/Paper  subtracted from:

Condition     Lower  Center   Upper   ---+---------+---------+---------+---
2Data/Paper  -10.88   -5.66  -0.439          (-------*------)
4DCom/MMD    -16.43  -11.25  -6.073   (------*------)
4DCom/Rte    -14.78   -9.46  -4.135     (------*-------)
                                      ---+---------+---------+---------+---
                                     -14.0      -7.0       0.0       7.0


Condition = 2Data/Paper  subtracted from:

Condition   Lower  Center    Upper   ---+---------+---------+---------+---
4DCom/MMD  -10.75  -5.591  -0.4292           (------*------)
4DCom/Rte   -9.10  -3.797   1.5090             (-------*------)
                                     ---+---------+---------+---------+---
                                    -14.0      -7.0       0.0       7.0


Condition = 4DCom/MMD  subtracted from:

Condition   Lower  Center  Upper   ---+---------+---------+---------+---
4DCom/Rte  -3.469   1.794  7.057                     (-------*------)
                                   ---+---------+---------+---------+---
                                  -14.0      -7.0       0.0       7.0


Tukey Simultaneous Tests
Response Variable Percent Head Up (Entire Run)
All Pairwise Comparisons among Levels of Condition
Condition = 1Voice/Paper  subtracted from:

             Difference       SE of            Adjusted
Condition      of Means  Difference  T-Value   P-Value
2Data/Paper       -5.66       2.034   -2.783    0.0277
4DCom/MMD        -11.25       2.017   -5.577    0.0000
4DCom/Rte         -9.46       2.073   -4.561    0.0000


Condition = 2Data/Paper  subtracted from:

           Difference       SE of            Adjusted
Condition    of Means  Difference  T-Value   P-Value
4DCom/MMD      -5.591       2.011   -2.780    0.0278
4DCom/Rte      -3.797       2.067   -1.837    0.2560


Condition = 4DCom/MMD  subtracted from:

           Difference       SE of            Adjusted
Condition    of Means  Difference  T-Value   P-Value
4DCom/Rte       1.794       2.050   0.8750    0.8178
```

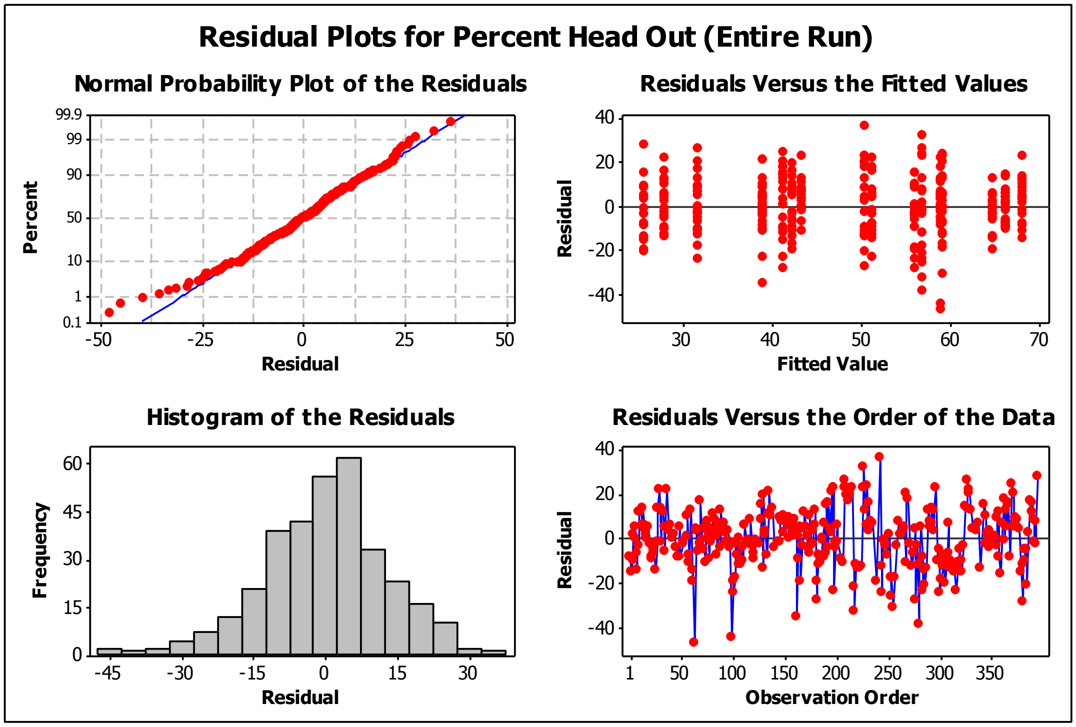


Figure 73. Residual plots for percent head up (entire run)

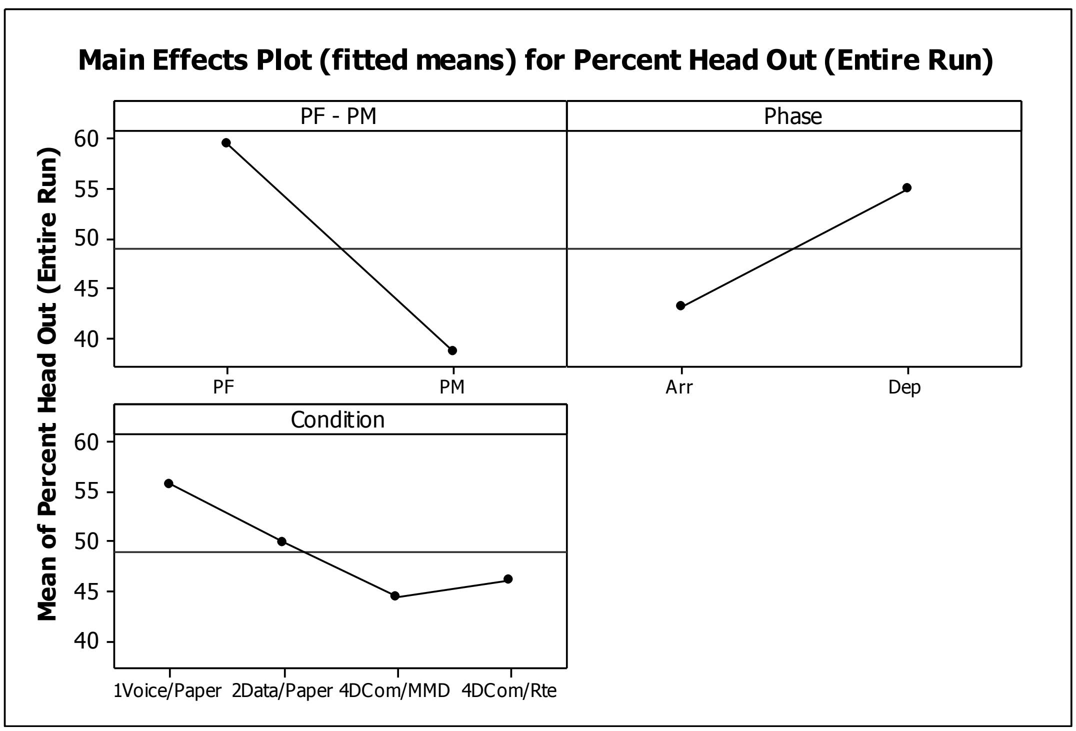


Figure 74. Main effects plot (fitted means) for percent head up (entire run)

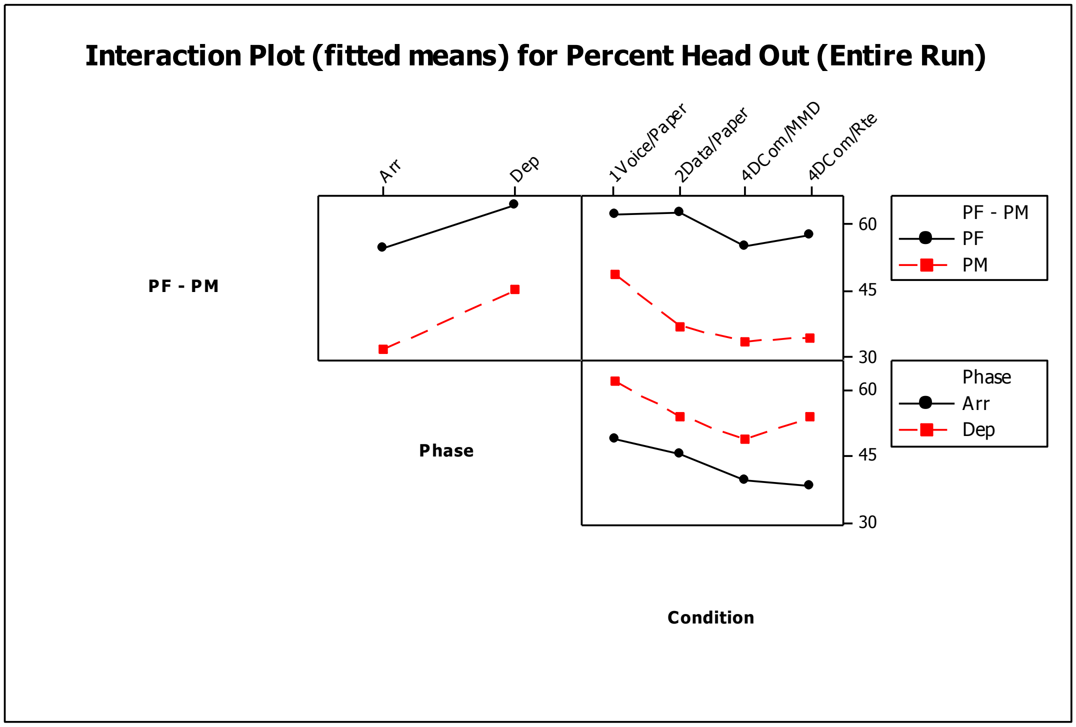


Figure 75. Interaction plot (fitted means) for percent head up (entire run)

Appendix O: Post-Scenario Questionnaire Results

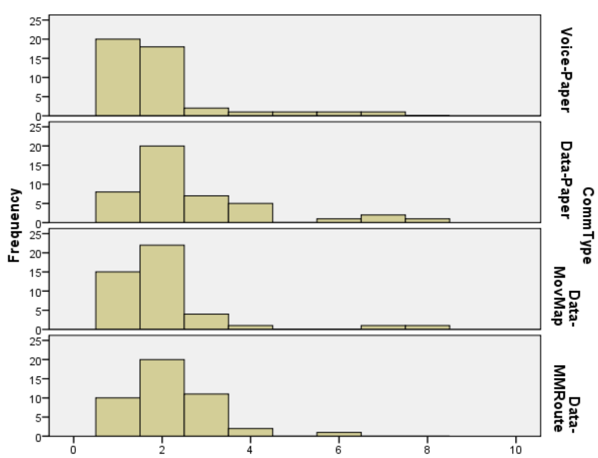
This Appendix presents results from the Post-Scenario Questionnaire (Appendix D). Data collected and analyzed for in flight operations occurred only in arrival scenarios, and surface operations occurred in both arrival and departure scenarios (departure scenarios terminated prior to takeoff). Therefore, for this experiment, "surface operations" and "taxi operations" are synonymous.

O.1 Workload (Bedford) rating

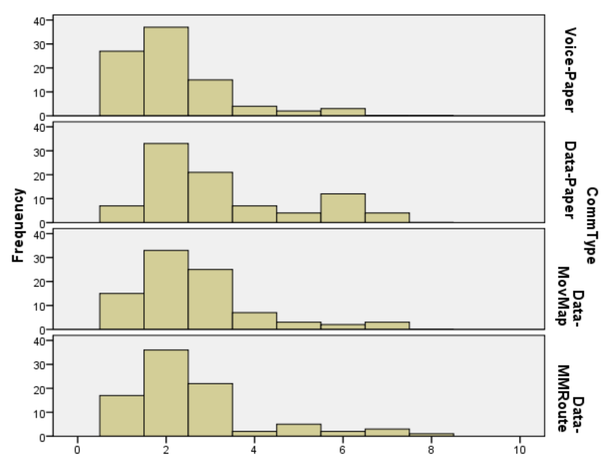
1) Your workload in-flight during arrivals

2) Your workload during surface operations

- 1 is "workload insignificant", 2 is "workload low", 3 is "enough spare capacity for all desirable additional tasks", and 10 is "task abandoned, pilot unable to apply sufficient effort".



1) Your workload in flight during arrivals



2) Your workload during surface / taxi operations

Table 46. Workload ratings: Inflight operations during arrivals

Role	Conditions	Median	Mean	Std. Deviation	N
PF	Voice/Paper	2.00	2.2273	1.63100	22
	DataComm/Paper	2.00	3.0909	1.79706	22
	DataComm/MMD	2.00	2.4545	1.79224	22
	DataComm/Route	2.00	2.3182	1.04135	22
PM	Voice/Paper	1.00	1.5909	.85407	22
	DataComm/Paper	2.00	2.2273	1.41192	22
	DataComm/MMD	2.00	1.6364	.65795	22
	DataComm/Route	2.00	2.0909	.97145	22

Table 47. Workload ratings: Surface operations during arrivals and departures

Role	Conditions	Median	Mean	Std. Deviation	N
PF	Voice/Paper	2.00	2.3409	1.23784	44
	DataComm/Paper	3.00	3.5227	1.75855	44
	DataComm/MMD	3.00	2.9318	1.64808	44
	DataComm/Route	2.00	2.4318	1.40427	44
PM	Voice/Paper	2.00	1.9773	1.10997	44
	DataComm/Paper	2.50	2.9318	1.60519	44
	DataComm/MMD	2.00	2.3409	.98697	44
	DataComm/Route	2.50	2.7727	1.64053	44

Table 48. Workload ratings: PF and PM mean Ranks

Seat	Inflight Workload N	Inflight Workload Mean Rank	Surface Workload N	Surface Workload Mean Rank
PF	88	99.34	176	184.45
PM	88	77.66	176	168.55
Total	176		352	

Table 49. Workload ratings: Binomial test of scale use

Role			Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (1-tailed)
PF	Inflight Workload.	Group 1	≤ 3	74	.84	.75	.028(a)
		Group 2	> 3	14	.16		
		Total		88	1.00		
	Surface Workload	Group 1	≤ 3	138	.78	.75	.009(a)
		Group 2	> 3	38	.22		
		Total		176	1.00		
PM	Inflight Workload.	Group 1	≤ 3	83	.94	.75	.000(a)
		Group 2	> 3	5	.06		
		Total		88	1.00		
	Surface Workload	Group 1	≤ 3	150	.85	.75	.000(a)
		Group 2	> 3	26	.15		
		Total		176	1.00		

a Based on Z Approximation.

Table 50. Workload ratings: Kruskal Wallis difference test for PF and PM

	Inflight Workload.	Surface Workload
Chi-Square	9.094	2.339
df	1	1
Asymp. Sig.	.003	.126

Table 51. Workload ratings: PF and PM Friedman Ranks difference by condition

Seat	Inflight_Wkld	Mean Rank		Surface_Wkld	Mean Rank
PF	Inflight_Wkld_C1	1.93		Surface_Wkld_C1	1.98
	Inflight_Wkld_C2	3.39		Surface_Wkld_C2	3.34
	Inflight_Wkld_C3	2.34		Surface_Wkld_C3	2.58
	Inflight_Wkld_C4	2.34		Surface_Wkld_C4	2.10
PM	Inflight_Wkld_C1	1.95		Surface_Wkld_C1	1.86
	Inflight_Wkld_C2	3.00		Surface_Wkld_C2	3.01
	Inflight_Wkld_C3	2.09		Surface_Wkld_C3	2.38
	Inflight_Wkld_C4	2.95		Surface_Wkld_C4	2.75

Table 52. Workload ratings: PF and PM test statistics

		Inflight_Wkld	Surface_Wkld
PF	N	22	44
	Chi-Square	28.525	43.603
	df	3	3
	Asymp. Sig.	.000	.000
PM	N	22	44
	Chi-Square	25.245	34.875
	df	3	3
	Asymp. Sig.	.000	.000

Table 53. Legend for superscript in workload pairwise comparisons tables

a.	Inflight_Wkld_C2 < Inflight_Wkld_C1		j.	Inflight_Wkld_C3 < Inflight_Wkld_C2
b.	Inflight_Wkld_C2 > Inflight_Wkld_C1		k.	Inflight_Wkld_C3 > Inflight_Wkld_C2
c.	Inflight_Wkld_C2 = Inflight_Wkld_C1		l.	Inflight_Wkld_C3 = Inflight_Wkld_C2
d.	Inflight_Wkld_C3 < Inflight_Wkld_C1		m.	Inflight_Wkld_C4 < Inflight_Wkld_C2
e.	Inflight_Wkld_C3 > Inflight_Wkld_C1		n.	Inflight_Wkld_C4 > Inflight_Wkld_C2
f.	Inflight_Wkld_C3 = Inflight_Wkld_C1		o.	Inflight_Wkld_C4 = Inflight_Wkld_C2
g.	Inflight_Wkld_C4 < Inflight_Wkld_C1		p.	Inflight_Wkld_C4 < Inflight_Wkld_C3
h.	Inflight_Wkld_C4 > Inflight_Wkld_C1		q.	Inflight_Wkld_C4 > Inflight_Wkld_C3
i.	Inflight_Wkld_C4 = Inflight_Wkld_C1		r.	Inflight_Wkld_C4 = Inflight_Wkld_C3

Table 54. Workload ratings: Pairwise comparisons Ranks of inflight operations during arrivals

Seat			N	Mean Rank	Sum of Ranks
PF	Inflight_Wkld_C2 - Inflight_Wkld_C1	Negative Ranks	0[a]	.00	.00
		Positive Ranks	16[b]	8.50	136.00
		Ties	6[c]		
		Total	22		
	Inflight_Wkld_C3 - Inflight_Wkld_C1	Negative Ranks	1[d]	4.00	4.00
		Positive Ranks	6[e]	4.00	24.00
		Ties	15[f]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C1	Negative Ranks	3[g]	7.83	23.50
		Positive Ranks	7[h]	4.50	31.50
		Ties	12[i]		
		Total	22		
	Inflight_Wkld_C3 - Inflight_Wkld_C2	Negative Ranks	12[j]	6.50	78.00
		Positive Ranks	0[k]	.00	.00
		Ties	10[l]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C2	Negative Ranks	11[m]	6.00	66.00
		Positive Ranks	0[n]	.00	.00
		Ties	11[o]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C3	Negative Ranks	3[p]	4.50	13.50
		Positive Ranks	3[q]	2.50	7.50
		Ties	16[r]		
		Total	22		
PM	Inflight_Wkld_C2 - Inflight_Wkld_C1	Negative Ranks	0[a]	.00	.00
		Positive Ranks	12[b]	6.50	78.00
		Ties	10[c]		
		Total	22		
	Inflight_Wkld_C3 - Inflight_Wkld_C1	Negative Ranks	2[d]	3.00	6.00
		Positive Ranks	3[e]	3.00	9.00
		Ties	17[f]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C1	Negative Ranks	0[g]	.00	.00
		Positive Ranks	11[h]	6.00	66.00
		Ties	11[i]		
		Total	22		
	Inflight_Wkld_C3 - Inflight_Wkld_C2	Negative Ranks	9[j]	5.00	45.00
		Positive Ranks	0[k]	.00	.00
		Ties	13[l]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C2	Negative Ranks	4[m]	4.38	17.50
		Positive Ranks	3[n]	3.50	10.50
		Ties	15[o]		
		Total	22		
	Inflight_Wkld_C4 - Inflight_Wkld_C3	Negative Ranks	0[p]	.00	.00
		Positive Ranks	10[q]	5.50	55.00
		Ties	12[r]		
		Total	22		

Table 55. Workload ratings: Pairwise comparisons Ranks for surface operations

Seat			N	Mean Rank	Sum of Ranks
PF	Surface_Wkld_C2 - Surface_Wkld_C1	Negative Ranks	5[a]	15.70	78.50
		Positive Ranks	32[b]	19.52	624.50
		Ties	7[c]		
		Total	44		
	Surface_Wkld_C3 - Surface_Wkld_C1	Negative Ranks	3[d]	17.17	51.50
		Positive Ranks	19[e]	10.61	201.50
		Ties	22[f]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C1	Negative Ranks	8[g]	9.94	79.50
		Positive Ranks	11[h]	10.05	110.50
		Ties	25[i]		
		Total	44		
	Surface_Wkld_C3 - Surface_Wkld_C2	Negative Ranks	26[j]	16.60	431.50
		Positive Ranks	7[k]	18.50	129.50
		Ties	11[l]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C2	Negative Ranks	29[m]	15.17	440.00
		Positive Ranks	1[n]	25.00	25.00
		Ties	14[o]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C3	Negative Ranks	16[p]	12.06	193.00
		Positive Ranks	6[q]	10.00	60.00
		Ties	22[r]		
		Total	44		
PM	Surface_Wkld_C2 - Surface_Wkld_C1	Negative Ranks	1[a]	8.00	8.00
		Positive Ranks	25[b]	13.72	343.00
		Ties	18[c]		
		Total	44		
	Surface_Wkld_C3 - Surface_Wkld_C1	Negative Ranks	5[d]	11.30	56.50
		Positive Ranks	16[e]	10.91	174.50
		Ties	23[f]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C1	Negative Ranks	0[g]	.00	.00
		Positive Ranks	21[h]	11.00	231.00
		Ties	23[i]		
		Total	44		
	Surface_Wkld_C3 - Surface_Wkld_C2	Negative Ranks	20[j]	13.35	267.00
		Positive Ranks	6[k]	14.00	84.00
		Ties	18[l]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C2	Negative Ranks	14[m]	11.07	155.00
		Positive Ranks	7[n]	10.86	76.00
		Ties	23[o]		
		Total	44		
	Surface_Wkld_C4 - Surface_Wkld_C3	Negative Ranks	5[p]	11.00	55.00
		Positive Ranks	13[q]	8.92	116.00
		Ties	26[r]		
		Total	44		

Table 56. Workload ratings: Pairwise comparisons test statistics (a) for inflight operations

Seat	Inflight_Wkld_ C2 - Inflight_Wkld_ C1 (b,b)	Inflight_Wkld_ C3 - Inflight_Wkld_ C1 (b,b)	Inflight_Wkld_ C4 - Inflight_Wkld_ C1 (b,b)	Inflight_Wkld_ C3 - Inflight_Wkld_ C2 (c,c)	Inflight_Wkld_ C4 - Inflight_Wkld_ C2 (c,c)	Inflight_Wkld_ C4 - Inflight_Wkld_ C3 (c,b)
PF	**-3.755[b]	-1.890[b]	-.432[b]	**-3.276[c]	**-3.022[c]	-.647[c]
PM	**-3.357[b]	-.447[b]	**-3.317[b]	**-2.807[c]	-.632[c]	**-3.162[b]

a. Wilcoxon Signed Ranks Test (Z), ** p<0.008 (alpha=0.05 Bonferroni adjusted)
b. Based on negative ranks, c. Based on positive ranks.

Table 57. Workload ratings: Pairwise comparisons test statistics (a) for surface operations

Seat	Surface_Wkld _C2 - Surface_Wkld _C1 (b,b)	Surface_Wkld_ C3 - Surface_Wkld_ C1 (b,b)	Surface_Wkld_ C4 - Surface_Wkld_ C1 (b,b)	Surface_Wkld_ C3 - Surface_Wkld_ C2 (c,c)	Surface_Wkld _C4 - Surface_Wkld _C2 (c,c)	Surface_Wkld_ C4 - Surface_Wkld_ C3 (c,b)
PF	**-4.245[b]	-2.499[b]	-.655[b]	**-2.789[c]	**-4.371[c]	-2.342[c]
PM	**-4.365[b]	-2.128[b]	**-4.200[b]	**-2.374[c]	-1.413[c]	**-1.345[b]

a. Wilcoxon Signed Ranks Test (Z), ** p<0.008 (alpha=0.05 Bonferroni adjusted)
b. Based on negative ranks, c. Based on positive ranks.

Table 58. Workload ratings: By message altitude band during arrivals

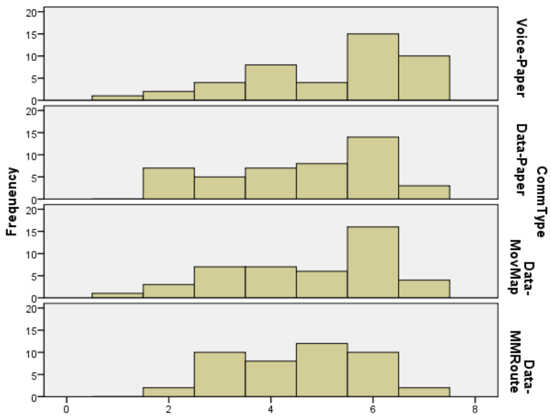
MsgAltitude		N	Mean	Std. Deviation	Minimum	Maximum
Low	Inflight Workload	43	2.1628	1.11120	1.00	7.00
	Surface Workload	44	2.9318	1.43701	1.00	6.00
	Condition	44	3.0000	.86266	2.00	4.00
Medium	Inflight Workload	43	2.3256	1.10671	1.00	6.00
	Surface Workload	44	3.2727	1.77008	1.00	8.00
	Condition	44	3.0909	.80169	2.00	4.00
High	Inflight Workload	44	2.1591	1.39673	1.00	7.00
	Surface Workload	44	2.8864	1.40126	1.00	7.00
	Condition	44	2.9091	.80169	2.00	4.00

Table 59. Workload ratings: Difference by condition within each altitude band

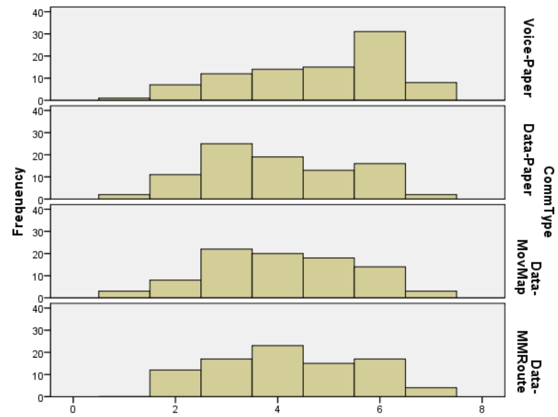
MsgAltitude		Surface Workload	Inflight Workload
Low	Chi-Square	1.602	1.157
	df	2	2
	Asymp. Sig.	.449	.561
Medium	Chi-Square	6.405	4.569
	df	2	2
	Asymp. Sig.	.041	.102
High	Chi-Square	.636	.614
	df	2	2
	Asymp. Sig.	.728	.736

O.2 Situation Awareness

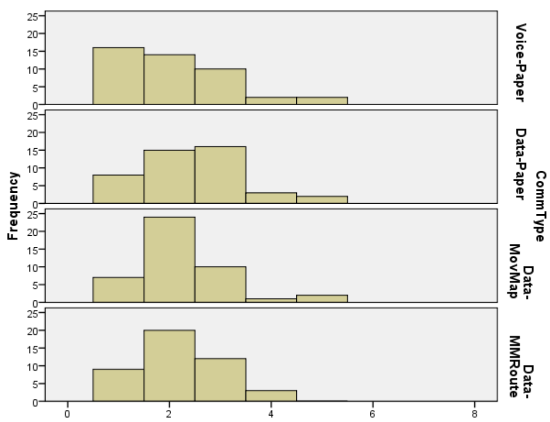
The left column are SA ratings in flight, the right column for surface. The top row is DEMAND ON ATTENTIONAL RESOURCES, the middle is SUPPLY OF ATTENTIONAL RESOURCES, and the bottom row is UNDERSTANDING OF THE SITUATION. Ratings were 1 = High and 7 = Low.



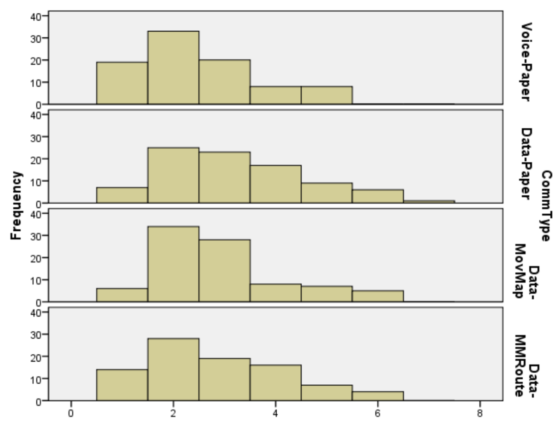
2A) Demand on Attentional Resource, In Flight



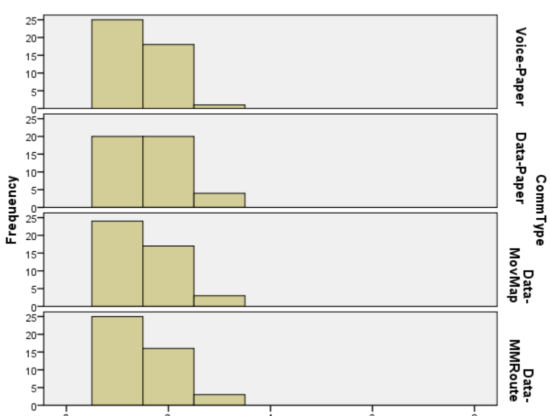
2B) Demand on Attentional Resource, Surface



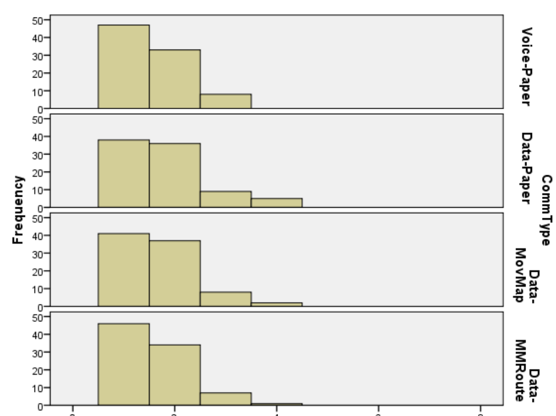
2C) Supply of Attentional Resource, In Flight



2D) Supply of Attentional Resource, Surface



2E) Understanding the Situation, In Flight



2F) Understanding the Situation, Surface Ops

Table 60. SART ratings: Inflight operations during arrivals

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	8.6818	2.80113	22
	DataComm/Paper	7.5455	2.36497	22
	DataComm/MMD	8.3182	2.51446	22
	DataComm/Route	8.4091	2.06234	22
	Total	8.2386	2.44477	88
PM	Voice/Paper	10.6364	2.59203	22
	DataComm/Paper	9.4545	2.44418	22
	DataComm/MMD	9.6818	2.31735	22
	DataComm/Route	9.2727	2.47236	22
	Total	9.7614	2.47281	88
Total	Voice/Paper	9.6591	2.84436	44
	DataComm/Paper	8.5000	2.56542	44
	DataComm/MMD	9.0000	2.48718	44
	DataComm/Route	8.8409	2.29198	44
	Total	9.0000	2.56793	176

Table 61. SART ratings: Surface operations during arrivals and departures

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	8.2273	2.45768	44
	DataComm/Paper	6.3864	2.72128	44
	DataComm/MMD	7.4318	2.46272	44
	DataComm/Route	7.9545	2.73610	44
	Total	7.5000	2.67047	176
PM	Voice/Paper	9.3636	2.91021	44
	DataComm/Paper	7.5909	3.01406	44
	DataComm/MMD	7.6136	2.69553	44
	DataComm/Route	7.6591	2.65841	44
	Total	8.0568	2.89969	176
Total	Voice/Paper	8.7955	2.73823	88
	DataComm/Paper	6.9886	2.91841	88
	DataComm/MMD	7.5227	2.56850	88
	DataComm/Route	7.8068	2.68610	88
	Total	7.7784	2.79739	352

Table 62. SART ratings: Surface operations during departures only

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	8.5455	2.57695	22
	DataComm/Paper	7.2727	2.71121	22
	DataComm/MMD	7.6364	2.23704	22
	DataComm/Route	8.5909	2.95456	22
	Total	8.0114	2.65007	88
PM	Voice/Paper	8.9091	3.06919	22
	DataComm/Paper	8.2727	2.91436	22
	DataComm/MMD	7.8182	2.77122	22
	DataComm/Route	8.3182	2.95016	22
	Total	8.3295	2.90351	88
Total	Voice/Paper	8.7273	2.80667	44
	DataComm/Paper	7.7727	2.82731	44
	DataComm/MMD	7.7273	2.49057	44
	DataComm/Route	8.4545	2.92109	44
	Total	8.1705	2.77631	176

Table 63. SART ratings: Surface operations during arrivals only

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	7.9091	2.34844	22
	DataComm/Paper	5.5000	2.48328	22
	DataComm/MMD	7.2273	2.70681	22
	DataComm/Route	7.3182	2.39814	22
	Total	6.9886	2.60633	88
PM	Voice/Paper	9.8182	2.73664	22
	DataComm/Paper	6.9091	3.02228	22
	DataComm/MMD	7.4091	2.66653	22
	DataComm/Route	7.0000	2.20389	22
	Total	7.7841	2.88655	88
Total	Voice/Paper	8.8636	2.69876	44
	DataComm/Paper	6.2045	2.82497	44
	DataComm/MMD	7.3182	2.65691	44
	DataComm/Route	7.1591	2.28181	44
	Total	7.3864	2.77100	176

Table 64. SART ratings: PF and PM difference test

	SART_DF	SART_SO	SART_Surface Departure	SART_Surface Arrival
Chi-Square	16.341	4.533	.872	4.450
df	1	1	1	1
Asymp. Sig.	.000	.033	.351	.035

Table 65. SART ratings: PF and PM difference by condition

Role		newSART_DF	newSART_SO	newSART_SurfaceDeparture	newSART_SurfaceArrival
PF	Chi-Square	2.723	10.649	2.982	10.342
	df	3	3	3	3
	Asymp. Sig.	.436	.014	.394	.016
PM	Chi-Square	5.205	12.332	1.875	15.459
	df	3	3	3	3
	Asymp. Sig.	.157	.006	.599	.001

Table 66. SART ratings: Pairwise comparisons for inflight operations

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
					Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	1.1364	.78159	-1.0422	3.3149
		DataComm/MMD	.3636	.80252	-1.8732	2.6005
		DataComm/Route	.2727	.74161	-1.7944	2.3398
	DataComm/Paper	Voice/Paper	-1.1364	.78159	-3.3149	1.0422
		DataComm/MMD	-.7727	.73595	-2.8241	1.2786
		DataComm/Route	-.8636	.66900	-2.7284	1.0011
	DataComm/MMD	Voice/Paper	-.3636	.80252	-2.6005	1.8732
		DataComm/Paper	.7727	.73595	-1.2786	2.8241
		DataComm/Route	-.0909	.69334	-2.0235	1.8416
	DataComm/Route	Voice/Paper	-.2727	.74161	-2.3398	1.7944
		DataComm/Paper	.8636	.66900	-1.0011	2.7284
		DataComm/MMD	.0909	.69334	-1.8416	2.0235
PM	Voice/Paper	DataComm/Paper	1.1818	.75956	-.9353	3.2990
		DataComm/MMD	.9545	.74127	-1.1116	3.0207
		DataComm/Route	1.3636	.76370	-.7650	3.4923
	DataComm/Paper	Voice/Paper	-1.1818	.75956	-3.2990	.9353
		DataComm/MMD	-.2273	.71808	-2.2288	1.7743
		DataComm/Route	.1818	.74121	-1.8842	2.2478
	DataComm/MMD	Voice/Paper	-.9545	.74127	-3.0207	1.1116
		DataComm/Paper	.2273	.71808	-1.7743	2.2288
		DataComm/Route	.4091	.72245	-1.6046	2.4228
	DataComm/Route	Voice/Paper	-1.3636	.76370	-3.4923	.7650
		DataComm/Paper	-.1818	.74121	-2.2478	1.8842
		DataComm/MMD	-.4091	.72245	-2.4228	1.6046

Dunnett C
Based on observed means.

Table 67. SART ratings: Pairwise comparisons for all surface operations

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
					Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	1.8409(*)	.55279	.3636	3.3182
		DataComm/MMD	.7955	.52452	-.6063	2.1972
		DataComm/Route	.2727	.55445	-1.2090	1.7545
	DataComm/Paper	Voice/Paper	-1.8409(*)	.55279	-3.3182	-.3636
		DataComm/MMD	-1.0455	.55330	-2.5241	.4332
		DataComm/Route	-1.5682(*)	.58176	-3.1229	-.0135
	DataComm/MMD	Voice/Paper	-.7955	.52452	-2.1972	.6063
		DataComm/Paper	1.0455	.55330	-.4332	2.5241
		DataComm/Route	-.5227	.55496	-2.0058	.9604
	DataComm/Route	Voice/Paper	-.2727	.55445	-1.7545	1.2090
		DataComm/Paper	1.5682(*)	.58176	.0135	3.1229
		DataComm/MMD	.5227	.55496	-.9604	2.0058
PM	Voice/Paper	DataComm/Paper	1.7727(*)	.63163	.0848	3.4607
		DataComm/MMD	1.7500(*)	.59801	.1519	3.3481
		DataComm/Route	1.7045(*)	.59422	.1165	3.2926
	DataComm/Paper	Voice/Paper	-1.7727(*)	.63163	-3.4607	-.0848
		DataComm/MMD	-.0227	.60959	-1.6518	1.6064
		DataComm/Route	-.0682	.60587	-1.6873	1.5510
	DataComm/MMD	Voice/Paper	-1.7500(*)	.59801	-3.3481	-.1519
		DataComm/Paper	.0227	.60959	-1.6064	1.6518
		DataComm/Route	-.0455	.57074	-1.5707	1.4798
	DataComm/Route	Voice/Paper	-1.7045(*)	.59422	-3.2926	-.1165
		DataComm/Paper	.0682	.60587	-1.5510	1.6873
		DataComm/MMD	.0455	.57074	-1.4798	1.5707

Dunnett C
Based on observed means.
* The mean difference is significant at the .05 level.

Table 68. SART ratings: Pairwise comparisons for surface departure operations

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
					Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	1.2727	.79748	-.9501	3.4956
		DataComm/MMD	.9091	.72754	-1.1188	2.9370
		DataComm/Route	-.0455	.83585	-2.3752	2.2843
	DataComm/Paper	Voice/Paper	-1.2727	.79748	-3.4956	.9501
		DataComm/MMD	-.3636	.74939	-2.4524	1.7252
		DataComm/Route	-1.3182	.85493	-3.7012	1.0648
	DataComm/MMD	Voice/Paper	-.9091	.72754	-2.9370	1.1188
		DataComm/Paper	.3636	.74939	-1.7252	2.4524
		DataComm/Route	-.9545	.79010	-3.1568	1.2477
	DataComm/Route	Voice/Paper	.0455	.83585	-2.2843	2.3752
		DataComm/Paper	1.3182	.85493	-1.0648	3.7012
		DataComm/MMD	.9545	.79010	-1.2477	3.1568
PM	Voice/Paper	DataComm/Paper	.6364	.90236	-1.8788	3.1515
		DataComm/MMD	1.0909	.88162	-1.3665	3.5483
		DataComm/Route	.5909	.90763	-1.9390	3.1208
	DataComm/Paper	Voice/Paper	-.6364	.90236	-3.1515	1.8788
		DataComm/MMD	.4545	.85741	-1.9353	2.8444
		DataComm/Route	-.0455	.88413	-2.5098	2.4189
	DataComm/MMD	Voice/Paper	-1.0909	.88162	-3.5483	1.3665
		DataComm/Paper	-.4545	.85741	-2.8444	1.9353
		DataComm/Route	-.5000	.86295	-2.9053	1.9053
	DataComm/Route	Voice/Paper	-.5909	.90763	-3.1208	1.9390
		DataComm/Paper	.0455	.88413	-2.4189	2.5098
		DataComm/MMD	.5000	.86295	-1.9053	2.9053

Dunnett C
Based on observed means.

Table 69. SART ratings: Pairwise comparisons for surface arrival operations

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	2.4091(*)	.72869	.3780	4.4402
		DataComm/MMD	.6818	.76402	-1.4478	2.8114
		DataComm/Route	.5909	.71561	-1.4037	2.5856
	DataComm/Paper	Voice/Paper	-2.4091(*)	.72869	-4.4402	-.3780
		DataComm/MMD	-1.7273	.78316	-3.9102	.4557
		DataComm/Route	-1.8182	.73601	-3.8697	.2333
	DataComm/MMD	Voice/Paper	-.6818	.76402	-2.8114	1.4478
		DataComm/Paper	1.7273	.78316	-.4557	3.9102
		DataComm/Route	-.0909	.77101	-2.2400	2.0581
	DataComm/Route	Voice/Paper	-.5909	.71561	-2.5856	1.4037
		DataComm/Paper	1.8182	.73601	-.2333	3.8697
		DataComm/MMD	.0909	.77101	-2.0581	2.2400
PM	Voice/Paper	DataComm/Paper	2.9091(*)	.86926	.4862	5.3320
		DataComm/MMD	2.4091(*)	.81463	.1385	4.6797
		DataComm/Route	2.8182(*)	.74913	.7301	4.9063
	DataComm/Paper	Voice/Paper	-2.9091(*)	.86926	-5.3320	-.4862
		DataComm/MMD	-.5000	.85930	-2.8951	1.8951
		DataComm/Route	-.0909	.79748	-2.3137	2.1319
	DataComm/MMD	Voice/Paper	-2.4091(*)	.81463	-4.6797	-.1385
		DataComm/Paper	.5000	.85930	-1.8951	2.8951
		DataComm/Route	.4091	.73755	-1.6467	2.4649
	DataComm/Route	Voice/Paper	-2.8182(*)	.74913	-4.9063	-.7301
		DataComm/Paper	.0909	.79748	-2.1319	2.3137
		DataComm/MMD	-.4091	.73755	-2.4649	1.6467

Dunnett C
Based on observed means.
* The mean difference is significant at the .05 level.

Table 70. SART ratings: During arrival scenario by message altitude

MsgAltitude		N	Mean	Std. Deviation	Minimum	Maximum
Low	SART_InFlight	22	8.6364	2.23704	4.00	12.00
	SART_Surface Ops	22	6.5455	2.21955	2.00	10.00
	Condition	22	3.0000	.87287	2.00	4.00
Medium	SART_DF	22	7.5909	2.51962	4.00	11.00
	SART_SurfaceArrival	22	5.4545	2.95566	.00	12.00
	Condition	22	3.0909	.81118	2.00	4.00
High	SART_DF	22	8.8182	2.63016	4.00	13.00
	SART_SurfaceArrival	20	6.7000	2.31926	2.00	12.00
	Condition	22	2.9091	.81118	2.00	4.00

Table 71. SART ratings: During arrival scenario by message altitude, test on conditions

MsgAltitude		SART Surface Ops in Arrivals	SART Inflight Operations
Low	Chi-Square	3.012	1.714
	df	2	2
	Asymp. Sig.	.222	.424
Medium	Chi-Square	6.162	1.307
	df	2	2
	Asymp. Sig.	.046	.520
High	Chi-Square	1.719	1.230
	df	2	2
	Asymp. Sig.	.423	.541

Table 72. SART ratings: Binomial test for PF and PM by condition

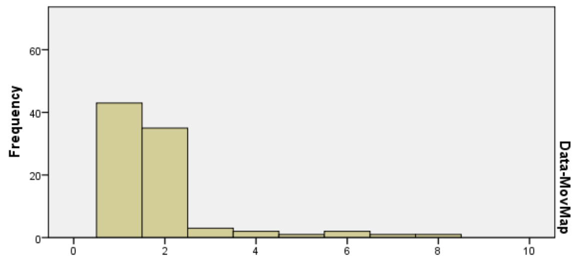
Role			Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (1-tailed)
PF	SART Inflight Operations	Group 1	≤ 4	10	.11	.75	.000(a,b)
		Group 2	> 4	78	.89		
		Total		88	1.00		
	SART Surface Operations	Group 1	≤ 4	23	.13	.75	.000(a,b)
		Group 2	> 4	153	.87		
		Total		176	1.00		
	SART Surface Ops in Departures	Group 1	≤ 4	10	.11	.75	.000(a,b)
		Group 2	> 4	78	.89		
		Total		88	1.00		
	SART Surface Ops in Arrivals	Group 1	≤ 4	13	.15	.75	.000(a,b)
		Group 2	> 4	75	.85		
		Total		88	1.00		
PM	SART Inflight Operations	Group 1	≤ 4	1	.01	.75	.000(a,b)
		Group 2	> 4	87	.99		
		Total		88	1.00		
	SART Surface Operations	Group 1	≤ 4	22	.13	.75	.000(a,b)
		Group 2	> 4	154	.88		
		Total		176	1.00		
	SART Surface Ops in Departures	Group 1	≤ 4	10	.11	.75	.000(a,b)
		Group 2	> 4	78	.89		
		Total		88	1.00		
	SART Surface Ops in Arrivals	Group 1	≤ 4	12	.14	.75	.000(a,b)
		Group 2	> 4	76	.86		
		Total		88	1.00		

a Alternative hypothesis states that the proportion of cases in the first group < .75.
b Based on Z Approximation.

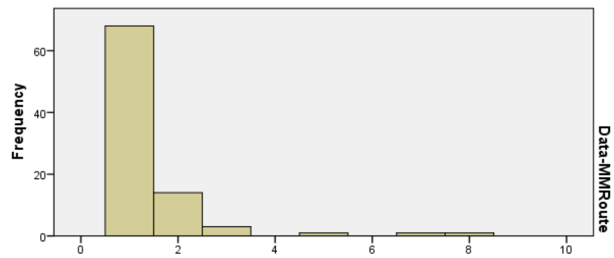
O.3 Acceptability of "Expected Taxi" and "Taxi" clearances

1) Did the display of the OWNSHIP POSITION on the navigation display make the taxi clearance easier to understand and to carry out? (1 – Easier, 7 – Not Easier, 8 – NA)

2) Did the display of the ROUTE on the navigation display make the taxi clearance easier to understand and to carry out? (1 – Easier, 7 – Not Easier, 8 – NA)



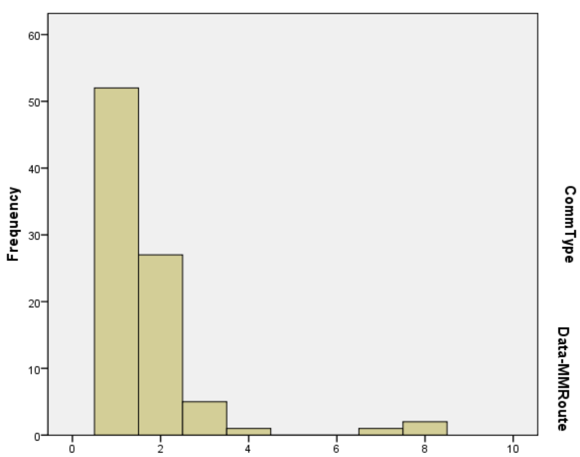
1) Ownship Position Make Clearance Easier To Understand



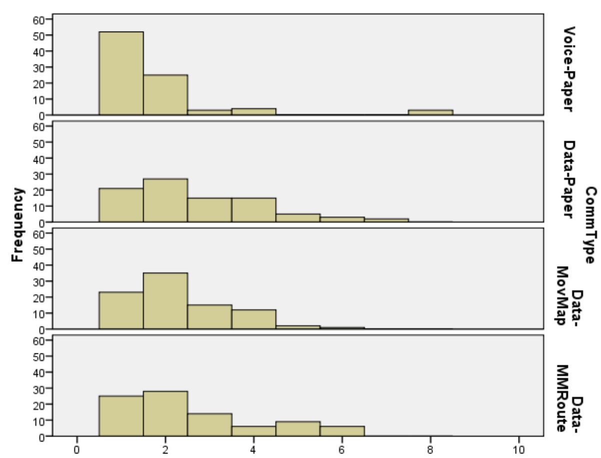
2) Route Displayed Make Clearance Easier To Understand

3) Did you have confidence that the taxi route was accurately depicted based on the Data Comm ATC instruction? (1 – confident route was accurate, 7 – not confident route was accurate, 8 – NA)

4) Did you have a sufficient amount of time to respond to the Voice or Data Comm transmitted messages? (1 – More than enough time, 7 – did not have enough time, 8 – NA)



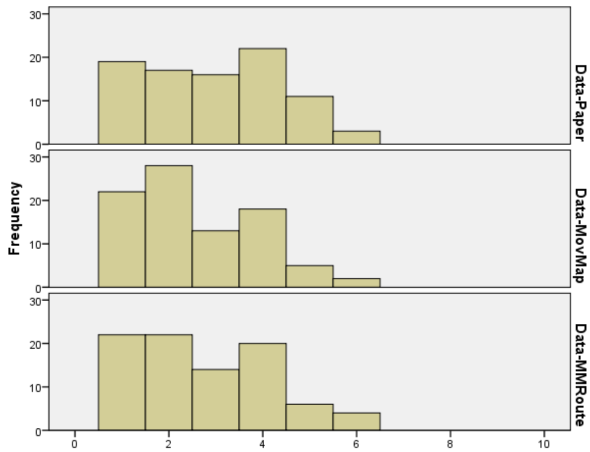
3) Confidence That Route Was Accurate



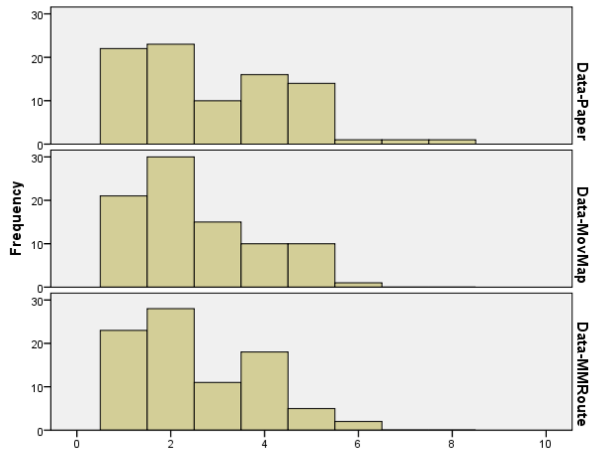
4) Sufficient Time to Respond to Messages

5) Was the amount of heads-down time required to receive and respond to just the “Expected Taxi” Data Comm messages acceptable in this scenario? (1 – minimal increase in Head Down time, 7 – too much Head Down time, 8 – NA)

6) Was the amount of heads-down time required to receive and respond to other non-time critical Data Comm messages acceptable in this scenario? (1 – minimal increase in Head Down time, 7 – too much Head Down time, 8 – NA)



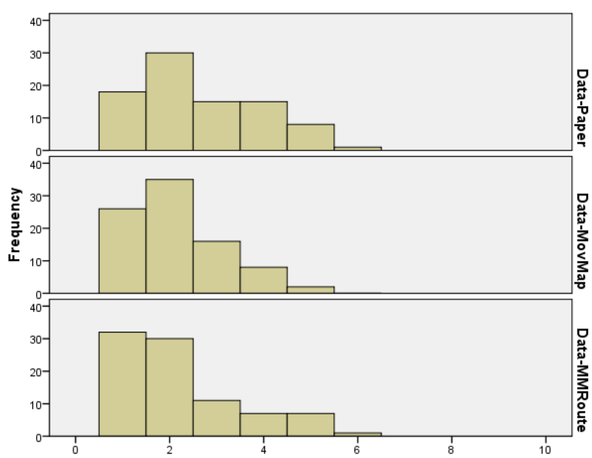
5) Head Down Time to Respond to Taxi Messages



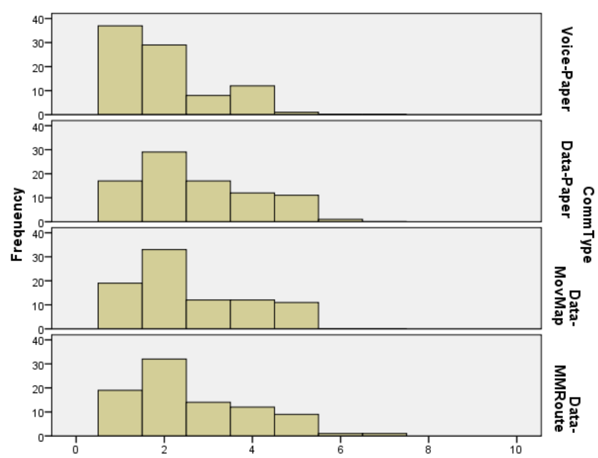
6) Head Down Time to Respond to Info Messages

7) Overall, was the communication mode (Voice or Data Comm) for receiving Expected and Taxi clearances acceptable during this scenario? (1 – Completely acceptable, 7 – completely unacceptable) [Note: this question was presented to the subjects only during Data Comm scenarios]

8) How much operational risk was introduced by the communication mode (Voice or Data Comm) used during this scenario? (1 – Extremely low risk, 7 – extremely high risk)

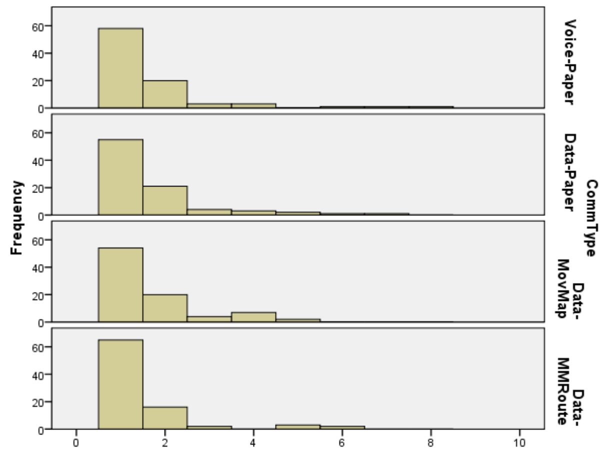


7) Communication Mode Acceptable



8) Operational Risk

9) Was there a point at which you did not feel that the transmitted taxi instructions were accurate? (1 – The message was accurate, 7 – the message was not accurate)



9) Accuracy of Taxi Instructions

Table 73. Acceptability ratings: Ownship helpful to understand clearance

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/MMD	1.9070	1.28756	43
	DataComm/Route	1.4545	.72991	44
	Total	1.6782	1.06197	87
PM	DataComm/MMD	1.6364	1.01365	44
	DataComm/Route	1.6136	1.22410	44
	Total	1.6250	1.11739	88

Table 74. Acceptability ratings: Route helpful to understand clearance

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/Route	1.3256	.74709	43
	Total	1.3256	.74709	43
PM	DataComm/Route	1.3636	1.01365	44
	Total	1.3636	1.01365	44

Table 75. Acceptability ratings: Confidence in route depiction

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/Route	1.6047	1.07215	43
	Total	1.6047	1.07215	43
PM	DataComm/Route	1.4651	.66722	43
	Total	1.4651	.66722	43

Table 76. Acceptability ratings: Sufficient time to respond to Voice or Data Comm message

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	1.6429	.85029	42
	DataComm/Paper	3.0227	1.48619	44
	DataComm/MMD	2.5227	1.06724	44
	DataComm/Route	2.7955	1.59329	44
	Total	2.5057	1.38007	174
PM	Voice/Paper	1.3810	.69677	42
	DataComm/Paper	2.3636	1.46416	44
	DataComm/MMD	2.0682	1.16933	44
	DataComm/Route	2.3864	1.49753	44
	Total	2.0575	1.30677	174

Table 77. Acceptability ratings: Head down time acceptable for "Expected Taxi" messages

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/Paper	3.3409	1.37998	44
	DataComm/MMD	2.8409	1.27486	44
	DataComm/Route	3.0000	1.52499	44
	Total	3.0606	1.40206	132
PM	DataComm/Paper	2.6136	1.46614	44
	DataComm/MMD	2.2955	1.35680	44
	DataComm/Route	2.5000	1.35544	44
	Total	2.4697	1.38938	132

Table 78. Acceptability ratings: Head down time for non-time-critical messages

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/Paper	3.3023	1.55126	43
	DataComm/MMD	2.8605	1.30167	43
	DataComm/Route	3.0000	1.38093	44
	Total	3.0538	1.41592	130
PM	DataComm/Paper	2.3409	1.39673	44
	DataComm/MMD	2.2500	1.33164	44
	DataComm/Route	2.0698	1.16282	43
	Total	2.2214	1.29668	131

Table 79. Acceptability ratings: Overall acceptability of Data Comm

Role	Conditions	Mean	Std. Deviation	N
PF	DataComm/Paper	3.0682	1.26487	44
	DataComm/MMD	2.4651	1.03162	43
	DataComm/Route	2.4318	1.40427	44
	Total	2.6565	1.26959	131
PM	DataComm/Paper	2.1860	1.20031	43
	DataComm/MMD	1.8182	.92190	44
	DataComm/Route	1.9773	1.15111	44
	Total	1.9924	1.09892	131

Table 80. Acceptability ratings: Operational risk imposed by communication mode

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	2.2558	1.19708	43
	DataComm/Paper	3.1591	1.34585	44
	DataComm/MMD	2.9070	1.30592	43
	DataComm/Route	2.8182	1.41869	44
	Total	2.7874	1.34966	174
PM	Voice/Paper	1.7045	.90424	44
	DataComm/Paper	2.2326	1.17184	43
	DataComm/MMD	2.2500	1.25984	44
	DataComm/Route	2.4318	1.35368	44
	Total	2.1543	1.20543	175

Table 81. Acceptability ratings: Taxi instructions considered accurate

Role	Conditions	Mean	Std. Deviation	N
PF	Voice/Paper	1.6667	1.18253	42
	DataComm/Paper	1.8864	1.29787	44
	DataComm/MMD	1.7674	.99612	43
	DataComm/Route	1.5455	1.13002	44
	Total	1.7168	1.15417	173
PM	Voice/Paper	1.4091	.92304	44
	DataComm/Paper	1.4186	1.00552	43
	DataComm/MMD	1.5455	1.08809	44
	DataComm/Route	1.4091	1.04143	44
	Total	1.4457	1.00925	175

Table 82. Acceptability ratings: PF and PM differences

	Chi-Square	df	Asymp. Sig.
Ownship Helpful To Understand Clearance	.759	1	.383
Route Helpful To Understand Clearance	.058	1	.809
Confidence in Route Depiction	.122	1	.727
Sufficient Time to Respond to Data Comm message	12.639	1	.000
Head Down Time Acceptable for Expected Taxi	12.159	1	.000
Head Down Time Acceptable for Non-Critical messages	24.162	1	.000
Overall Acceptability of Data Comm	20.665	1	.000
Operational Risk Imposed	20.966	1	.000
Taxi Instructions Considered Accurate	12.102	1	.001

Table 83. Acceptability ratings: PF and PM differences by condition

	Role					
	PF			PM		
	Chi-Square	df	Asymp. Sig.	Chi-Square	df	Asymp. Sig.
Ownship Helpful To Understand Clearance	3.656	1	.056	.787	1	.375
Route Helpful To Understand Clearance	27.653	3	.000	18.974	3	.000
Confidence in Route Depiction	3.138	2	.208	1.188	2	.552
Sufficient Time to Respond to Data Comm message	1.822	2	.402	.556	2	.757
Head Down Time Acceptable for Expected Taxi	7.958	2	.019	1.891	2	.389
Head Down Time Acceptable for Non-Critical msgs	10.673	3	.014	9.946	3	.019
Overall Acceptability of Data Comm	4.616	3	.202	.874	3	.832

Table 84. Acceptability ratings: Pairwise comparisons for sufficient time to respond by condition

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	95% Confidence Interval Lower Bound
PF	Voice/Paper	DataComm/Paper	-1.3799(*)	.25964	-2.0741	-.6857
		DataComm/MMD	-.8799(*)	.20761	-1.4351	-.3246
		DataComm/Route	-1.1526(*)	.27370	-1.8844	-.4208
	DataComm/Paper	Voice/Paper	1.3799(*)	.25964	.6857	2.0741
		DataComm/MMD	.5000	.27584	-.2372	1.2372
		DataComm/Route	.2273	.32847	-.6505	1.1051
	DataComm/MMD	Voice/Paper	.8799(*)	.20761	.3246	1.4351
		DataComm/Paper	-.5000	.27584	-1.2372	.2372
		DataComm/Route	-.2727	.28910	-1.0453	.4999
	DataComm/Route	Voice/Paper	1.1526(*)	.27370	.4208	1.8844
		DataComm/Paper	-.2273	.32847	-1.1051	.6505
		DataComm/MMD	.2727	.28910	-.4999	1.0453
PM	Voice/Paper	DataComm/Paper	-.9827(*)	.24552	-1.6391	-.3263
		DataComm/MMD	-.6872(*)	.20648	-1.2393	-.1351
		DataComm/Route	-1.0054(*)	.25005	-1.6739	-.3369
	DataComm/Paper	Voice/Paper	.9827(*)	.24552	.3263	1.6391
		DataComm/MMD	.2955	.28248	-.4595	1.0504
		DataComm/Route	-.0227	.31574	-.8665	.8211
	DataComm/MMD	Voice/Paper	.6872(*)	.20648	.1351	1.2393
		DataComm/Paper	-.2955	.28248	-1.0504	.4595
		DataComm/Route	-.3182	.28643	-1.0837	.4473
	DataComm/Route	Voice/Paper	1.0054(*)	.25005	.3369	1.6739
		DataComm/Paper	.0227	.31574	-.8211	.8665
		DataComm/MMD	.3182	.28643	-.4473	1.0837

Dunnett C
Based on observed means.
* The mean difference is significant at the .05 level.

Table 85. Acceptability ratings: Pairwise comparisons for "Expected Taxi" message head down time

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	95% Confidence Interval Lower Bound
PF	DataComm/Paper	DataComm/MMD	.5000	.28323	-.1875	1.1875
		DataComm/Route	.3409	.31006	-.4117	1.0936
	DataComm/MMD	DataComm/Paper	-.5000	.28323	-1.1875	.1875
		DataComm/Route	-.1591	.29965	-.8865	.5683
	DataComm/Route	DataComm/Paper	-.3409	.31006	-1.0936	.4117
		DataComm/MMD	.1591	.29965	-.5683	.8865
PM	DataComm/Paper	DataComm/MMD	.3182	.30115	-.4128	1.0492
		DataComm/Route	.1136	.30101	-.6171	.8443
	DataComm/MMD	DataComm/Paper	-.3182	.30115	-1.0492	.4128
		DataComm/Route	-.2045	.28913	-.9064	.4973
	DataComm/Route	DataComm/Paper	-.1136	.30101	-.8443	.6171
		DataComm/MMD	.2045	.28913	-.4973	.9064

Dunnett C
Based on observed means.

Table 86. Acceptability ratings: Pairwise comparisons for non-time-critical message head down time

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	95% Confidence Interval Lower Bound
PF	DataComm/Paper	DataComm/MMD	.4419	.30882	-.3084	1.1921
		DataComm/Route	.3023	.31512	-.4630	1.0676
	DataComm/MMD	DataComm/Paper	-.4419	.30882	-1.1921	.3084
		DataComm/Route	-.1395	.28765	-.8381	.5590
	DataComm/Route	DataComm/Paper	-.3023	.31512	-1.0676	.4630
		DataComm/MMD	.1395	.28765	-.5590	.8381
PM	DataComm/Paper	DataComm/MMD	.0909	.29093	-.6153	.7971
		DataComm/Route	.2711	.27529	-.3973	.9396
	DataComm/MMD	DataComm/Paper	-.0909	.29093	-.7971	.6153
		DataComm/Route	.1802	.26786	-.4702	.8307
	DataComm/Route	DataComm/Paper	-.2711	.27529	-.9396	.3973
		DataComm/MMD	-.1802	.26786	-.8307	.4702

Dunnett C
Based on observed means.

Table 87. Acceptability ratings: Pairwise comparisons for overall acceptability of Data Comm

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	95% Confidence Interval Lower Bound
PF	DataComm/Paper	DataComm/MMD	.6031(*)	.24721	.0028	1.2033
		DataComm/Route	.6364	.28492	-.0553	1.3280
	DataComm/MMD	DataComm/Paper	-.6031(*)	.24721	-1.2033	-.0028
		DataComm/Route	.0333	.26376	-.6071	.6737
	DataComm/Route	DataComm/Paper	-.6364	.28492	-1.3280	.0553
		DataComm/MMD	-.0333	.26376	-.6737	.6071
PM	DataComm/Paper	DataComm/MMD	.3679	.22983	-.1903	.9261
		DataComm/Route	.2088	.25223	-.4038	.8213
	DataComm/MMD	DataComm/Paper	-.3679	.22983	-.9261	.1903
		DataComm/Route	-.1591	.22233	-.6988	.3806
	DataComm/Route	DataComm/Paper	-.2088	.25223	-.8213	.4038
		DataComm/MMD	.1591	.22233	-.3806	.6988

Dunnett C
Based on observed means.
* The mean difference is significant at the .05 level.

Table 88. Acceptability ratings: Pairwise comparisons for operational risk by condition

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	-.9033(*)	.27293	-1.6330	-.1736
		DataComm/MMD	-.6512	.27016	-1.3738	.0715
		DataComm/Route	-.5624	.28119	-1.3141	.1894
	DataComm/Paper	Voice/Paper	.9033(*)	.27293	.1736	1.6330
		DataComm/MMD	.2521	.28430	-.5080	1.0122
		DataComm/Route	.3409	.29480	-.4469	1.1287
	DataComm/MMD	Voice/Paper	.6512	.27016	-.0715	1.3738
		DataComm/Paper	-.2521	.28430	-1.0122	.5080
		DataComm/Route	.0888	.29224	-.6925	.8701
	DataComm/Route	Voice/Paper	.5624	.28119	-.1894	1.3141
		DataComm/Paper	-.3409	.29480	-1.1287	.4469
		DataComm/MMD	-.0888	.29224	-.8701	.6925
PM	Voice/Paper	DataComm/Paper	-.5280	.22476	-1.1290	.0730
		DataComm/MMD	-.5455	.23379	-1.1702	.0793
		DataComm/Route	-.7273(*)	.24542	-1.3831	-.0714
	DataComm/Paper	Voice/Paper	.5280	.22476	-.0730	1.1290
		DataComm/MMD	-.0174	.26078	-.7147	.6798
		DataComm/Route	-.1993	.27126	-.9245	.5260
	DataComm/MMD	Voice/Paper	.5455	.23379	-.0793	1.1702
		DataComm/Paper	.0174	.26078	-.6798	.7147
		DataComm/Route	-.1818	.27878	-.9268	.5632
	DataComm/Route	Voice/Paper	.7273(*)	.24542	.0714	1.3831
		DataComm/Paper	.1993	.27126	-.5260	.9245
		DataComm/MMD	.1818	.27878	-.5632	.9268

Dunnett C
Based on observed means.
* The mean difference is significant at the .05 level.

Table 89. Acceptability ratings: Pairwise comparisons for taxi instruction accuracy by condition

Role	(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
					Upper Bound	Lower Bound
PF	Voice/Paper	DataComm/Paper	-.2197	.26754	-.9353	.4959
		DataComm/MMD	-.1008	.23742	-.7362	.5347
		DataComm/Route	.1212	.24963	-.5466	.7890
	DataComm/Paper	Voice/Paper	.2197	.26754	-.4959	.9353
		DataComm/MMD	.1189	.24771	-.5433	.7811
		DataComm/Route	.3409	.25943	-.3524	1.0342
	DataComm/MMD	Voice/Paper	.1008	.23742	-.5347	.7362
		DataComm/Paper	-.1189	.24771	-.7811	.5433
		DataComm/Route	.2220	.22825	-.3882	.8322
	DataComm/Route	Voice/Paper	-.1212	.24963	-.7890	.5466
		DataComm/Paper	-.3409	.25943	-1.0342	.3524
		DataComm/MMD	-.2220	.22825	-.8322	.3882
PM	Voice/Paper	DataComm/Paper	-.0095	.20707	-.5632	.5441
		DataComm/MMD	-.1364	.21511	-.7112	.4385
		DataComm/Route	.0000	.20979	-.5607	.5607
	DataComm/Paper	Voice/Paper	.0095	.20707	-.5441	.5632
		DataComm/MMD	-.1268	.22455	-.7272	.4735
		DataComm/Route	.0095	.21946	-.5772	.5963
	DataComm/MMD	Voice/Paper	.1364	.21511	-.4385	.7112
		DataComm/Paper	.1268	.22455	-.4735	.7272
		DataComm/Route	.1364	.22706	-.4704	.7432
	DataComm/Route	Voice/Paper	.0000	.20979	-.5607	.5607
		DataComm/Paper	-.0095	.21946	-.5963	.5772
		DataComm/MMD	-.1364	.22706	-.7432	.4704

Dunnett C
Based on observed means.

Table 90. Acceptability ratings: By message altitude band

MsgAltitude		N	Mean	Std. Deviation	Minimum	Maximum
Low	Sufficient Time to Respond to message	44	3.1136	1.67354	1.00	6.00
	Overall Acceptability of Data Comm	44	2.4545	1.37172	1.00	5.00
	Operational Risk Imposed	44	2.9318	1.46902	1.00	5.00
	Taxi Instructions Accurate	44	1.7273	1.42018	1.00	7.00
Med	Sufficient Time to Respond to message	44	2.8182	1.60338	1.00	7.00
	Overall Acceptability of Data Comm	44	2.7045	1.51856	1.00	6.00
	Operational Risk Imposed	44	3.0227	1.54752	1.00	7.00
	Taxi Instructions Accurate	44	1.8636	1.24995	1.00	5.00
High	Sufficient Time to Respond to message	44	2.5682	1.26487	1.00	6.00
	Overall Acceptability of Data Comm	43	2.4884	1.22226	1.00	5.00
	Operational Risk Imposed	43	2.9070	1.34189	1.00	5.00
	Taxi Instructions Accurate	43	1.8605	1.42397	1.00	6.00

Table 91. Acceptability ratings: Differences by altitude band

MsgAltitude		Sufficient Time to Repond	Overall Acceptable	Operational Risk Imposed	Taxi Instructions Accurate
Low	Chi-Square	6.507	1.159	.336	2.433
	df	2	2	2	2
	Asymp. Sig.	.039	.560	.845	.296
Med	Chi-Square	3.997	6.509	3.117	4.034
	df	2	2	2	2
	Asymp. Sig.	.136	.039	.210	.133
High	Chi-Square	.937	5.163	.098	3.273
	df	2	2	2	2
	Asymp. Sig.	.626	.076	.952	.195

Table 92. Acceptability ratings: Binomial test

Role			Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (1-tailed)
PF	Ownship Helpful To Understand Clearance	Group 1	≤ 4	84	.97	.75	.000(a)
		Group 2	> 4	3	.03		
		Total		87	1.00		
	Route Helpful To Understand Clearance	Group 1	≤ 4	42	.98	.75	.000(a)
		Group 2	> 4	1	.02		
		Total		43	1.00		
	Confidence in Route Depiction	Group 1	≤ 4	42	.98	.75	.000(a)
		Group 2	> 4	1	.02		
		Total		43	1.00		
	Sufficient Time to Respond	Group 1	≤ 4	157	.90	.75	.000(a)
		Group 2	> 4	17	.10		
		Total		174	1.00		
	Head Down Time Acceptable for Taxi msg	Group 1	≤ 4	114	.86	.75	.001(a)
		Group 2	> 4	18	.14		
		Total		132	1.00		
	Head Down Time Acceptable for Info msg	Group 1	≤ 4	107	.82	.75	.031(a)
		Group 2	> 4	23	.18		
		Total		130	1.00		
	Overall Acceptability	Group 1	≤ 4	118	.90	.75	.000(a)
		Group 2	> 4	13	.10		
		Total		131	1.00		
	Operational Risk Imposed	Group 1	≤ 4	152	.87	.75	.000(a)
		Group 2	> 4	22	.13		
		Total		174	1.00		
	Taxi Instructions Accurate	Group 1	≤ 4	167	.97	.75	.000(a)
		Group 2	> 4	6	.03		
		Total		173	1.00		
PM	Ownship Helpful To Understand Clearance	Group 1	≤ 4	84	.95	.75	.000(a)
		Group 2	> 4	4	.05		
		Total		88	1.00		
	Route Helpful To Understand Clearance	Group 1	≤ 4	43	.98	.75	.000(a)
		Group 2	> 4	1	.02		
		Total		44	1.00		
	Confidence in Route Depiction	Group 1	≤ 4	43	1.00	.75	.000(a)
		Group 2	> 4	0	.00		
		Total		43	1.00		
	Sufficient Time to Respond	Group 1	≤ 4	163	.94	.75	.000(a)
		Group 2	> 4	11	.06		
		Total		174	1.00		
	Head Down Time Acceptable for Taxi msg	Group 1	≤ 4	119	.90	.75	.000(a)
		Group 2	> 4	13	.10		
		Total		132	1.00		
	Head Down Time Acceptable for Info msg	Group 1	≤ 4	120	.92	.75	.000(a)
		Group 2	> 4	11	.08		
		Total		131	1.00		
	Overall Acceptability	Group 1	≤ 4	125	.95	.75	.000(a)
		Group 2	> 4	6	.05		
		Total		131	1.00		
	Operational Risk Imposed	Group 1	≤ 4	162	.93	.75	.000(a)
		Group 2	> 4	13	.07		
		Total		175	1.00		
	Taxi Instructions Accurate	Group 1	≤ 4	168	.96	.75	.000(a)
		Group 2	> 4	7	.04		
		Total		175	1.00		

a Based on Z Approximation.

Appendix P: Post-Experiment Questionnaire Results

This Appendix presents results from the Post-Experiment Questionnaire (Appendix E).

P.1 Workload Comparison

Table 93. Workload ratings: Levene's test of equality

F	df1	df2	Sig.
.938	7	80	.482

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+DisplayCond+Seat+DisplayCond * Seat

Table 94. Workload ratings: Tests of between subjects effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5.466[a]	7	.781	116.871	.000	.911
Intercept	20.920	1	20.920	3130.952	.000	.975
DisplayCond	5.459	3	1.820	272.309	.000	.911
Seat	.000	1	.000	.030	.862	.000
DisplayCond * Seat	.008	3	.003	.379	.768	.014
Error	.535	80	.007			
Total	26.921	88				
Corrected Total	6.001	87				

a. R Squared = .911 (Adjusted R Squared = .903)

Table 95. Workload ratings: By Condition and PF and PM

DisplayCond	Seat	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	PF	.312	.025	.263	.361
	PM	.337	.025	.288	.386
MMD	PF	.537	.025	.488	.586
	PM	.514	.025	.465	.563
RTE	PF	.879	.025	.830	.928
	PM	.873	.025	.824	.922
VP	PF	.216	.025	.167	.265
	PM	.233	.025	.184	.282

Table 96. Workload ratings: By display condition

Display Cond	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	.325	.017	.290	.359
MMD	.526	.017	.491	.560
RTE	.876	.017	.841	.911
VP	.224	.017	.190	.259

Table 97. Workload ratings: By crew position

Seat	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
PF	.486	.012	.462	.511
PM	.489	.012	.465	.514

Table 98. Workload ratings: Multiple comparisons of display condition

(I) Display Cond	(J) Display Cond	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	MMD	-.2010*	.02465	.000	-.2657	-.1364
	RTE	-.5514*	.02465	.000	-.6161	-.4867
	VP	.1001*	.02465	.001	.0355	.1648
MMD	DP	.2010*	.02465	.000	.1364	.2657
	RTE	-.3504*	.02465	.000	-.4150	-.2857
	VP	.3012*	.02465	.000	.2365	.3658
RTE	DP	.5514*	.02465	.000	.4867	.6161
	MMD	.3504*	.02465	.000	.2857	.4150
	VP	.6515*	.02465	.000	.5869	.7162
VP	DP	-.1001*	.02465	.001	-.1648	-.0355
	MMD	-.3012*	.02465	.000	-.3658	-.2365
	RTE	-.6515*	.02465	.000	-.7162	-.5869

Based on observed means.

*. The mean difference is significant at the .05 level.

P.2 Situation Awareness

Table 99. SA ratings: Levene's test of equality

F	df1	df2	Sig.
2.106	7	80	.052

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+DisplayCond+Seat+DisplayCond * Seat

Table 100. SA ratings: Test of between subject effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5.877[a]	7	.840	333.695	.000	.967
Intercept	20.861	1	20.861	8290.713	.000	.990
DisplayCond	5.866	3	1.955	777.067	.000	.967
Seat	9.46E-005	1	9.46E-005	.038	.847	.000
DisplayCond * Seat	.012	3	.004	1.543	.210	.055
Error	.201	80	.003			
Total	26.940	88				
Corrected Total	6.079	87				

a. R Squared = .967 (Adjusted R Squared = .964)

Table 101. SA ratings: Means by display condition

DisplayCond	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
DP	.323	.011	.302	.344
MMD	.520	.011	.499	.541
RTE	.892	.011	.870	.913
VP	.213	.011	.192	.235

Table 102. SA ratings: Means by crew position

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
PF	.486	.008	.471	.501
PM	.488	.008	.473	.503

Table 103. SA ratings: Means by display condition and by crew position

DisplayCond	Seat	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	PF	.310	.015	.280	.340
	PM	.335	.015	.305	.365
MMD	PF	.511	.015	.481	.541
	PM	.529	.015	.499	.559
RTE	PF	.909	.015	.879	.939
	PM	.874	.015	.844	.904
VP	PF	.213	.015	.183	.243
	PM	.213	.015	.183	.243

Table 104. SA ratings: Mean differences by display condition

(I) DisplayCond	(J) DisplayCond	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	MMD	-.1972*	.01512	.000	-.2369	-.1575
	RTE	-.5687*	.01512	.000	-.6084	-.5290
	VP	.1095*	.01512	.000	.0699	.1492
MMD	DP	.1972*	.01512	.000	.1575	.2369
	RTE	-.3715*	.01512	.000	-.4112	-.3319
	VP	.3067*	.01512	.000	.2670	.3464
RTE	DP	.5687*	.01512	.000	.5290	.6084
	MMD	.3715*	.01512	.000	.3319	.4112
	VP	.6783*	.01512	.000	.6386	.7179
VP	DP	-.1095*	.01512	.000	-.1492	-.0699
	MMD	-.3067*	.01512	.000	-.3464	-.2670
	RTE	-.6783*	.01512	.000	-.7179	-.6386

Based on observed means.

*. The mean difference is significant at the .05 level.

P.3 Acceptability of Expected Taxi Data Comm message

	Controller to send Expected Taxi msg		Flight crew to respond to message (1)	
	YES	NO	YES	NO
Data Comm with paper				
Above 10,000 feet MSL	22		20	
Below 10,000 feet MSL	17	5	11	9
Final Approach Fix through roll-out	3	19		20
Taxiing Surface Operations	20	2	17	3
Data Comm with Moving Map				
Above 10,000 feet MSL	22		20	
Below 10,000 feet MSL	18	4	13	7
Final Approach Fix through roll-out	3	19	1	19
Taxiing Surface Operations	22		19	1
Data Comm with MMD and route				
Above 10,000 feet MSL	22		20	
Below 10,000 feet MSL	18	4	12	8
Final Approach Fix through roll-out	4	18	2	18
Taxiing Surface Operations	21	1	18	2

1) Used outdated questionnaire for Crew 1, therefore no question about flight crew response

No change as a function of display mode:
1A, 1B, 2A, 2B, 3B, 4A, 5A, 5B, 6A, 6B, 7B,8A, 9A, 9B, 10A, 10B, 11A, 11B

Change:
3A: felt crew could respond between FAF and rollout in MMD + route mode
4A: felt "Expected Taxi" messages should not be sent during taxi when in paper mode
7A: felt messages during paper mode, and flight crew should not have to respond < 10,000 feet
7B, 8A: same regardless of mode, however thought crews should not have to respond <10,000 feet
8B: response depended on mode, no Data Comm FAF to roll out in paper mode

Error (?):
4B said no "Expected Taxi" messages when in MMD + route mode, otherwise okay.

P.4 Trust in the System

Display comparisons were made by each crew member, comparing one display against each other. The analysis sought to determine the pilot's preference when considering least workload, highest situation awareness, highest crew coordination and highest trust. A consistency index subsequent to the AHP analysis suggests that the scores were inconsistent, meaning that the rater's priorities were loaded toward an actual preference. The AHP indicates the MMD+Route, in nearly all cases, was the preferred display across the constructs. The consistency index confirms this conclusion with variable scores across the displays and the highest preference for the MMD+Route.

Table 105. Trust ratings: AHP preference analysis

			Workload				SA				Crew Coordination				Trust			
Crew	Sub No	Seat	WLVP	WLDP	WLMMD	WLRTE	SAVP	SADP	SAMMD	SARTE	CCVP	CCDP	CCMMD	CCRTE	TRVP	TRDP	TRMMD	TRRTE
1	1	PF	0.06	0.08	0.26	0.60	0.06	0.11	0.25	0.58	0.06	0.08	0.26	0.60	0.06	0.11	0.25	0.58
1	2	PM	0.05	0.10	0.22	0.63	0.04	0.11	0.21	0.63	0.05	0.10	0.22	0.63	0.04	0.11	0.21	0.63
2	3	PF	0.05	0.08	0.24	0.63	0.05	0.10	0.24	0.61	0.08	0.09	0.24	0.59	0.08	0.09	0.19	0.65
2	4	PM	0.06	0.08	0.25	0.61	0.05	0.10	0.24	0.62	0.07	0.13	0.15	0.66	0.07	0.13	0.27	0.53
3	5	PF	0.04	0.09	0.24	0.64	0.04	0.08	0.24	0.64	0.03	0.09	0.24	0.63	0.04	0.09	0.21	0.66
3	6	PM	0.04	0.10	0.25	0.61	0.04	0.09	0.24	0.63	0.03	0.09	0.24	0.63	0.04	0.09	0.25	0.63
4	7	PF	0.04	0.09	0.25	0.62	0.05	0.08	0.28	0.60	0.05	0.09	0.25	0.61	0.06	0.10	0.22	0.62
4	8	PM	0.04	0.11	0.23	0.62	0.04	0.11	0.27	0.57	0.06	0.12	0.25	0.58	0.05	0.10	0.22	0.63
5	9	PF	0.04	0.09	0.24	0.64	0.04	0.09	0.23	0.64	0.04	0.08	0.24	0.64	0.04	0.09	0.23	0.65
5	10	PM	0.05	0.09	0.24	0.63	0.04	0.08	0.22	0.65	0.05	0.09	0.24	0.62	0.07	0.13	0.27	0.53
6	11	PF	0.04	0.09	0.24	0.63	0.04	0.10	0.25	0.61	0.05	0.09	0.22	0.64	0.04	0.11	0.31	0.54
6	12	PM	0.04	0.09	0.24	0.63	0.04	0.10	0.25	0.61	0.04	0.09	0.22	0.65	0.04	0.11	0.31	0.54
7	13	PF	0.08	0.20	0.48	0.24	0.06	0.09	0.21	0.64	0.05	0.11	0.24	0.60	0.05	0.10	0.25	0.59
7	14	PM	0.04	0.10	0.25	0.61	0.04	0.09	0.23	0.65	0.05	0.11	0.24	0.60	0.07	0.13	0.27	0.53
8	15	PF	0.04	0.09	0.25	0.62	0.05	0.09	0.24	0.63	0.04	0.10	0.25	0.61	0.04	0.10	0.24	0.61
8	16	PM	0.05	0.08	0.24	0.63	0.04	0.08	0.26	0.61	0.04	0.08	0.24	0.63	0.04	0.08	0.24	0.63
9	17	PF	0.05	0.07	0.23	0.66	0.05	0.10	0.23	0.63	0.05	0.10	0.22	0.63	0.04	0.10	0.23	0.62
9	18	PM	0.06	0.07	0.20	0.67	0.04	0.11	0.23	0.62	0.04	0.10	0.22	0.64	0.06	0.11	0.25	0.58
10	19	PF	0.04	0.09	0.23	0.65	0.04	0.11	0.24	0.61	0.04	0.10	0.23	0.62	0.07	0.13	0.27	0.53
10	20	PM	0.13	0.35	0.28	0.24	0.08	0.23	0.40	0.28	0.07	0.10	0.35	0.48	0.05	0.09	0.23	0.62
11	21	PF	0.05	0.10	0.24	0.62	0.04	0.09	0.23	0.65	0.04	0.09	0.23	0.65	0.05	0.12	0.26	0.58
11	22	PM	0.04	0.10	0.26	0.59	0.04	0.12	0.26	0.58	0.04	0.11	0.26	0.60	0.05	0.11	0.24	0.61

Table 106. Trust ratings: Weighted responses for consistency

			Workload				SA				Crew Coordination				Trust			
Crew	Sub No	Seat	WLVP	WLDP	WLMMD	WLRTE	SAVP	SADP	SAMMD	SARTE	CCVP	CCDP	CCMMD	CCRTE	TRVP	TRDP	TRMMD	TRRTE
1	1	PF	0.05	0.10	0.25	0.60	0.05	0.10	0.62	0.22	0.06	0.09	0.27	0.58	0.06	0.13	0.25	0.55
1	2	PM	0.10	0.12	0.25	0.54	0.05	0.11	0.22	0.62	0.06	0.12	0.23	0.60	0.05	0.13	0.22	0.60
2	3	PF	0.06	0.08	0.25	0.61	0.05	0.11	0.25	0.59	0.09	0.10	0.24	0.57	0.08	0.10	0.21	0.62
2	4	PM	0.06	0.08	0.27	0.59	0.05	0.11	0.24	0.60	0.07	0.14	0.18	0.61	0.07	0.15	0.27	0.51
3	5	PF	0.04	0.12	0.25	0.58	0.05	0.11	0.26	0.59	0.04	0.13	0.25	0.58	0.05	0.11	0.22	0.62
3	6	PM	0.05	0.12	0.26	0.57	0.05	0.11	0.25	0.59	0.04	0.13	0.25	0.58	0.05	0.12	0.25	0.58
4	7	PF	0.05	0.12	0.26	0.58	0.05	0.09	0.29	0.57	0.05	0.10	0.26	0.58	0.07	0.14	0.23	0.57
4	8	PM	0.05	0.14	0.23	0.58	0.05	0.14	0.27	0.55	0.06	0.13	0.25	0.56	0.06	0.12	0.23	0.59
5	9	PF	0.04	0.12	0.25	0.58	0.04	0.12	0.24	0.59	0.05	0.11	0.26	0.59	0.05	0.11	0.24	0.60
5	10	PM	0.05	0.10	0.25	0.60	0.05	0.11	0.23	0.61	0.06	0.11	0.24	0.59	0.07	0.15	0.27	0.51
6	11	PF	0.05	0.11	0.25	0.59	0.04	0.12	0.25	0.58	0.05	0.11	0.23	0.61	0.04	0.14	0.31	0.51
6	12	PM	0.05	0.11	0.25	0.59	0.04	0.12	0.25	0.58	0.05	0.12	0.23	0.61	0.04	0.14	0.31	0.51
7	13	PF	0.08	0.18	0.42	0.32	0.06	0.11	0.23	0.61	0.06	0.13	0.25	0.56	0.06	0.12	0.27	0.55
7	14	PM	0.05	0.12	0.25	0.58	0.05	0.11	0.24	0.60	0.06	0.13	0.25	0.56	0.07	0.15	0.27	0.51
8	15	PF	0.04	0.12	0.26	0.58	0.05	0.10	0.24	0.60	0.05	0.12	0.25	0.58	0.05	0.12	0.25	0.58
8	16	PM	0.05	0.09	0.26	0.60	0.05	0.10	0.27	0.58	0.05	0.10	0.25	0.60	0.05	0.10	0.25	0.60
9	17	PF	0.05	0.08	0.26	0.62	0.05	0.11	0.24	0.59	0.05	0.13	0.23	0.59	0.05	0.13	0.24	0.58
9	18	PM	0.06	0.08	0.23	0.63	0.04	0.13	0.23	0.59	0.04	0.12	0.23	0.60	0.06	0.13	0.25	0.55
10	19	PF	0.05	0.11	0.24	0.60	0.05	0.13	0.25	0.57	0.05	0.12	0.24	0.59	0.07	0.15	0.27	0.51
10	20	PM	0.14	0.35	0.27	0.24	0.08	0.24	0.40	0.28	0.08	0.12	0.35	0.44	0.06	0.12	0.24	0.58
11	21	PF	0.05	0.13	0.25	0.57	0.05	0.11	0.24	0.60	0.05	0.11	0.24	0.60	0.06	0.14	0.26	0.54
11	22	PM	0.05	0.13	0.26	0.55	0.05	0.14	0.26	0.55	0.04	0.13	0.26	0.57	0.06	0.13	0.24	0.57

Abbreviations:

WLVP	Workload, Voice/Paper	SAVP	SA, Voice/Paper	CCVP	Crew coordination, Voice/Paper	TRVP	Trust, Voice/Paper
WLDP	Workload, DataComm/Paper	SADP	SA, DataComm/Paper	CCDP	Crew coordination, DataComm/Paper	TRDP	Trust, DataComm/Paper
WLMMD	Workload, Moving Map Display	SAMMD	SA, Moving Map Display	CCMMD	Crew coordination, Moving Map Display	TRMMD	Trust, Moving Map Display
WLRTE	Workload, MMD+Route	SARTE	SA, MMD+Route	CCRTE	Crew coordination, MMD+Route	TRRTE	Trust, MMD+Route

P.5 Crew Coordination

Table 107. Crew coordination: Levene's test of equality

F	df1	df2	Sig.
1.498	7	80	.180

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+DisplayCond+Seat+DisplayCond * Seat

Table 108. Crew coordination: Test for between subject effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6.021[a]	7	.860	821.140	.000	.986
Intercept	20.885	1	20.885	19938.362	.000	.996
DisplayCond	6.019	3	2.006	1915.420	.000	.986
Seat	3.34E-005	1	3.34E-005	.032	.859	.000
DisplayCond * Seat	.002	3	.001	.562	.642	.021
Error	.084	80	.001			
Total	26.990	88				
Corrected Total	6.105	87				

a. R Squared = .986 (Adjusted R Squared = .985)

Table 109. Crew coordination: Mean ratings by display condition

DisplayCond	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
DP	.317	.007	.303	.331
MMD	.509	.007	.495	.523
RTE	.903	.007	.889	.916
VP	.220	.007	.206	.234

Table 110. Crew coordination: Mean rating by crew position

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
PF	.487	.005	.477	.496
PM	.488	.005	.478	.497

Table 111. Crew coordination: Mean rating by display condition and crew position

Display Cond	Seat	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	1.00	.309	.010	.290	.329
	2.00	.324	.010	.305	.344
MMD	1.00	.509	.010	.490	.529
	2.00	.509	.010	.489	.528
RTE	1.00	.908	.010	.888	.927
	2.00	.898	.010	.878	.917
VP	1.00	.220	.010	.200	.239
	2.00	.220	.010	.201	.240

Table 112. Crew coordination: Pairwise comparison by display condition

(I) Display Cond	(J) Display Cond	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DP	MMD	-.1922*	.00976	.000	-.2178	-.1666
	RTE	-.5858*	.00976	.000	-.6114	-.5602
	VP	.0971*	.00976	.000	.0714	.1227
MMD	DP	.1922*	.00976	.000	.1666	.2178
	RTE	-.3936*	.00976	.000	-.4192	-.3680
	VP	.2892*	.00976	.000	.2636	.3148
RTE	DP	.5858*	.00976	.000	.5602	.6114
	MMD	.3936*	.00976	.000	.3680	.4192
	VP	.6829*	.00976	.000	.6573	.7085
VP	DP	-.0971*	.00976	.000	-.1227	-.0714
	MMD	-.2892*	.00976	.000	-.3148	-.2636
	RTE	-.6829*	.00976	.000	-.7085	-.6573

Based on observed means.

*. The mean difference is significant at the .05 level.

P.6 Summary

The results of the post-experiment summary questions (Appendix E.6) are tabulated here.

#1: To what degree did the scenarios in this experiment accurately simulate a complex, high-workload environment? If not, what was missing? (Scale of 1 "realistic" to 7 "unrealistic")

Rating	Number of responses	Comments (number of crews making the comment)
1	5	very good (one crew rated ground ops 1 and inflight ops 5)
2	12	add flight crew interaction (1) ; have more radio comm while airborne (1)
3	1	allow use of auto-pilot, have more comm while airborne (1)
4	1	ground operations very good, however airborne operations were generic
5	2	need more radio comm while airborne (ground ops very good)
6	0	
7	0	
Mean=2.6	N = 21	The first crew (2 pilots) were not asked this question, one crew scored twice

#2: What is your overall assessment of the potential of communicating clearance updates or changes using data link while an aircraft is taxiing or in busy terminal area? (Scale of 1 "realistic" to 7 "unrealistic")

Rating	Number of responses	Comments (number of crews making the comment)
1	3	
2	13	if immediate response not required (2); close to implementable as in experiment (2)
3	2	
4	0	
5	2	getting new clearance so close to taxiway intersection is problematic (1); prefer Voice so I am in the communication loop of what other aircraft are doing (1)
6	2	fairly unrealistic (1)
7	0	
Mean=2.6	N = 22	

#3: Should the dotted cyan lines for an "Expected Taxi" clearance include red hold short bars?

Rating	Number of responses	Comments (number of crews making the comment)
Yes	17	
No	3	
-	N = 20	The first crew (2 pilots) were not asked this question

#4: Will the solid magenta line for a Taxi clearance on the ND encourage crew members to begin taxiing prior to receiving the Voice message from ATC?

Rating	Number of responses	Comments (number of crews making the comment)
Yes	4	need to add text to end of Data Comm message saying "Contact ATC xxx.xx" (1)
Maybe	11	however training and operational procedures should be sufficient (11)
No	5	
-	N = 20	The first crew (2 pilots) were not asked this question

#5: Was the simultaneous Voice and Data Comm instructions to cross active runway clear? Was there a delay in the FO updating the graphical display on the ND? Was the delay important?

Rating	Number of responses	Comments (number of crews making the comment)
Yes	16	but not a good time to be Head Down (1); high workload as implemented (1); Voice comm should have priority (1); delay responding until across the runway (1)
No	3	Data Comm probably not necessary (1); did not like going Head Down (1)
-	N = 19	The first crew (2 pilots) were not asked this question, one crew did not respond

#6: How would CDTI impact your workload, SA, and acceptability of using Data Comm messages in terminal airspace or surface operations?

Rating n/a	Number of responses	Comments (number of crews making the comment)
-	16	helpful, increase in SA outweighs possible increase in workload, less Voice comm
-	1	may cause overload, but very useful in low visibility conditions
-	2	might cause more Head Down time, but eliminate confusion, less radio congestion
-	1	would slow down operations if information too cluttered
-	N = 20	The first crew (2 pilots) were not asked this question

#7: Was the use of Voice by the controller for critical or time sensitive information (such as crossing the runway) appropriate and necessary?

Rating	Number of responses	Comments (number of crews making the comment)
Yes	20	Voice is quicker; has priority for crew attention; hard time trusting Data Comm
No	0	
-	N = 20	The first crew (2 pilots) were not asked this question

#8: Were there any challenges with Data Comm unique to your flight duties as PF or PM?

Rating n/a	Number of responses	Comments (number of crews making the comment)
-	4	significant increase in Head Down time and workload for the PM
-	2	difficult for the PF to stay in the information loop; a challenge to keep crew member informed; prioritizing messages and tasks
-	2	difficult keeping CDU and ND aligned; respond on second CDU page caused errors and too much Head Down time
-	N = 8	The first crew (2 pilots) were not asked this question, many crews did not respond

#9: Do you have any other comments?

Rating n/a	Number of responses	Comments (number of crews making the comment)
-	4	like and prefer Data Comm, very useful if integrated with MMD and route, otherwise limited benefit except for language barriers
-	4	no Data Comm messages when time critical, safety related, or on runway
-	2	entire airspace system would greatly benefit from this enhancement in safety, the sooner the better for all, looking forward to seeing this on the flight line
-	1	use a different color or bold text to show most recent clearance
-	N = 11	The first crew (2 pilots) were not asked this question, many crews did not respond

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01- 06 - 2013

2. REPORT TYPE
Technical Publication

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Flight Crew Workload, Acceptability, and Performance When Using Data Comm in a High-Density Terminal Area Simulation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Norman, R. Michael; Baxley, Brian T.; Adams, Catherine A.; Ellis, Kyle K. E.; Latorella, Kara A.; Comstock, James R., Jr

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
031102.02.07.06.9D36.09

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-19907

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TP-2013-218007

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 03
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
NASA and the FAA collaborated to conduct a simulator experiment using 22 commercial airline pilots to determine the effect of using Data Comm to issue messages during busy, terminal area operations. Four equipage conditions were used: Voice communication only, Data Comm only, Data Comm with Moving Map Display, and Data Comm with Moving Map displaying taxi route. Each condition was used in an arrival and a departure scenario at Boston Logan Airport. Of particular interest was the flight crew response to D-TAXI, the use of Data Comm by Air Traffic Control (ATC) to send taxi instructions. Quantitative data was collected on subject reaction time, flight technical error, operational errors, and eye tracking information. Questionnaires collected subjective feedback on workload, situation awareness, and acceptability to the flight crew. Results showed that 95% of the Data Comm messages were responded to by the flight crew within one minute and 97% of the messages within two minutes, and flight crews reported the Expected D-TAXI messages as useful. Flight crews reported the use of Data Comm as unacceptable when issuing instructions to cross an active runway, and issuing D-TAXI messages between the Final Approach Fix and 80 knots during landing roll.

15. SUBJECT TERMS
Air traffic control; Data communication; Datalinked taxi routes; Pilot workload

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	254	STI Help Desk (email: help@sti.nasa.gov) (443) 757-5802