

The Impact of Data Communications Messages in the Terminal Area on Flight Crew Workload and Performance

A NASA / FAA Collaborative Study

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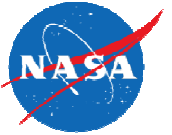
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Project Sponsors and Support



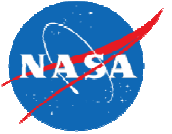
NASA / FAA Interagency Agreement
Technical Direction 1 to IA1-973



NASA Aviation Safety Program, Integrated Intelligent Flight Deck
Project

NASA Airspace Systems Program

Introduction



Description of Topic

Use of Data Comm for operations in the terminal area and on the surface will be prevalent by 2022 to enable more efficient operations and increase capacity. Geared primarily to assist controllers, information transferred via Data Comm could include flight and taxi clearances, weather, and 4D trajectories.

Problem Statements

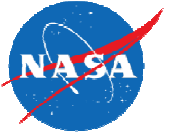
How does the use of Data Comm (D-TAXI) in the terminal area and on the surface impact the flight crews' workload and awareness, and is it considered acceptable

- arrival, taxi-in, and taxi-out operations using Voice or Data Comm
- explore impact of "Taxi", "Expected Taxi", and "Amended Taxi" clearances

How does the acceptability of Data Comm vary with aircraft equipage

- paper, moving map with ownship position, moving map with taxi route

Literature Review



What We Think We Know

Voice: efficient, fast, party-line Situation Awareness (SA), congested, mistakes, accents, missed messages

Data Comm: accurate, persistent, cumbersome, loss of SA, focused attention

Cockpit equipage: first-order effect on crew workload and acceptability

What We Don't Know

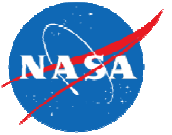
Workload and acceptability of CPDLC Data Comm messages in terminal operations

How display methodology impacts flight crew workload and acceptability

Literature Review

1. FAA: Data Comm HF paper (HFWG-08), Flight Simulator Evaluation of Baseline Crew Performance with 3 Data Link Interfaces, NextGen HF in Data Comm
2. NASA: Eval of Mixed-Mode Data-Link Comm for NextGen, Integrating Datalink and Cockpit Display Technologies into Current and Future Taxi Operations
3. Europe: D-TAXI, EMMA, EMMA2, HF Issues with Airborne Data Link, LINK 2000+
4. Academic: Influence of Datalink Display Format on Pilot Performance

Statement of Purpose



Purpose

Obtain, analyze, and provide meaningful flight crew data to the FAA to contribute to defining requirements of Data Comm operations in the terminal area.

-- Independent Variables based on FAA needs and past research:

- 1) communication modality (Voice, Data Comm)
- 2) display methodology (paper, map with ownship, map with ownship & route)

-- Variables of interest include flight crew acceptability and workload

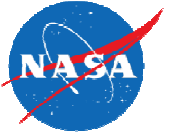
Metrics

1. Post-run & post-experiment questionnaires
2. Oculometer data (eye gaze, dwell time, heads up/heads down)
3. Flight technical performance (nose wheel rate, flight director deviation)

Assumptions

1. Real-world operations to the maximum extent possible; align with FAA TC work
2. High-density current day Voice scenario; intrusive worst-case Data Comm scenario

Participants



Participants

4 pilots as Subject Matter Experts to assist in experiment checkout in January 2010
-- all very experienced US Airways pilots (2 were also Check Airman)

22 current, qualified, B757/767 pilots from American, Continental, Delta, US Airways
-- crews from the same airline and fly in the position they currently hold

	Ave Age	Low Age	High Age	Ave Yrs	Low Yrs	High Yrs	Ave Hrs	Ave B757 Hrs
Capt	52	46	58	24	19	33	17,600	7300
FO	44	37	56	15	10	26	11,200	5000

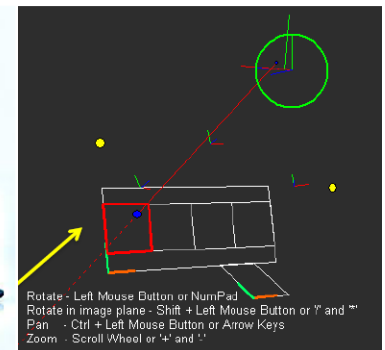
Voice Communications

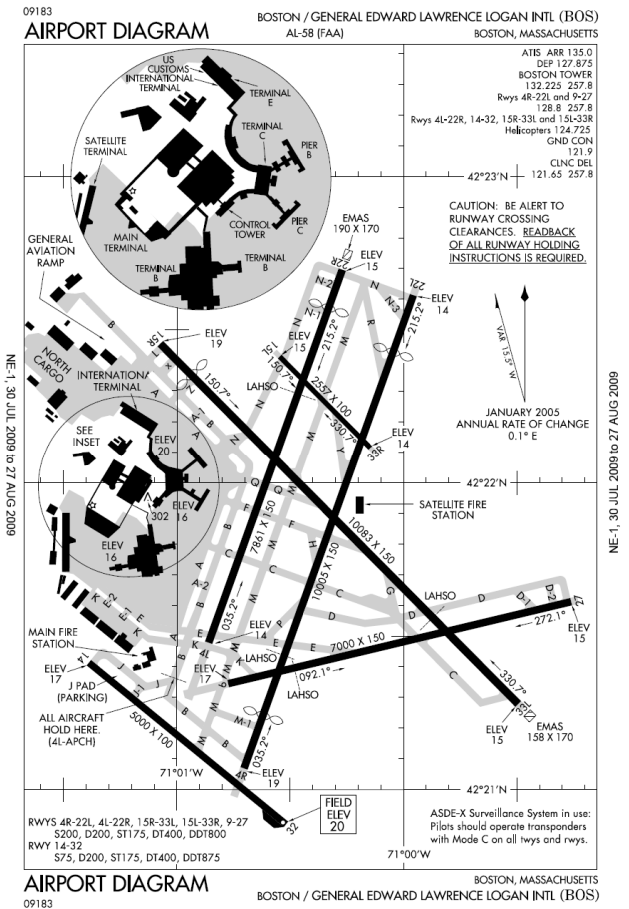
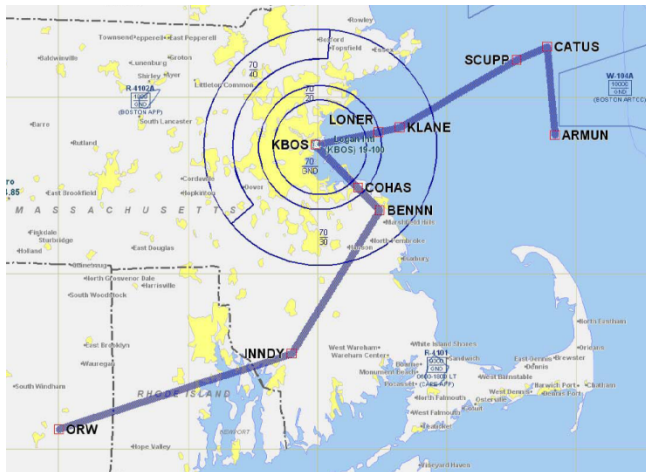
Over 200 aircraft and 1200 associated audio files per subject crew during 16 scenarios
-- ATIS, Ground, Tower, and Approach pre-recorded human voices
-- Voice comm from other aircraft were pre-recorded synthesized messages
-- Communications from the Ground Crew and Cabin Crew were live human voices

Simulation and Equipment Integration Flight Deck (IFD)

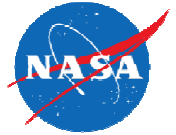
http://scap.hq.nasa.gov/docs/SCAP_FLIGHTSIM_112508_508.pdf

- Fixed-base flight simulation of a Boeing 757-200 cockpit
 - standard layout for PFD, ND, EICAS, flight instruments, gear, flaps, throttle, dual CDUs, ...
- Current data base of KBOS (Boston) airfield and navigation aids
- Visual panorama system with 200 degrees horizontal and 40 degrees vertical FOV.
- PEGASUS FMS; B747 FANS 1/A Data Comm
- 10 camera SmartEye remote eye-tracking system
 - 5 cameras per crew member
- Scripted traffic with audio files (78 per hour)





Experiment Design



High-fidelity simulation of operationally realistic, high-density, normal operations

- current day typical Voice scenarios, intrusive Data Comm scenarios
- no emergencies or abnormal procedures, however operational errors possible
- day Visual Meteorological Conditions (increase workload through visual lookout)
- 20 aircraft per scenario; 2 aircraft in every Arrival scenario were a factor for look-out
- Data Comm messages given at 7 different altitudes, landing roll-out, and taxi ops

“Expected Taxi”, “ATIS”, and “Altimeter” messages varied by altitude during arrival scenarios as a function of crew

“Taxi” and “Amended Taxi” messages were sent during high-workload times

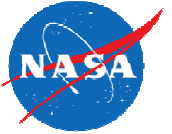
Voice scenarios did not include “Expected Taxi” or “Amended Taxi” clearances

Crew instructed to respond to Voice and Data Comm messages as soon as practicable consistent with workload

Captain flies, FO operates Data Comm

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

Data Comm Uplink Messages



Sample arrival and depart messages:

KBOS ALTIMETER 29.90

KBOS ATIS INDIA CURRENT

PUSHBACK AT xxxxZ

CLEARED TO START

EXPECT TAXI TO RW 27 VIA A.C.D

TAXI TO RW 27 VIA A.F.M.C.D HOLD SHORT RW 33L

AMENDED TAXI TO RW 27 VIA F.H.RW22L.C.D HOLD SHORT RW 33L

CONTACT BOS TOWER 132.22

AMENDED TAXI TO RW 27 VIA D HOLD SHORT RW 27

Pre-loaded messages during arrivals:

CROSS ARMUM AT FL180

CONTACT BOS APP 120.6

CROSS SCUPP AT 11,000 FT 230 KTS

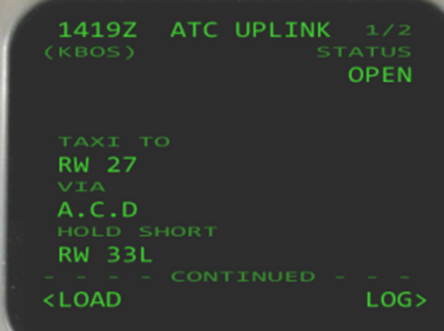
- NOTE: specific subset of CPDLC messages selected to scope this experiment to stay within Segment 2 timeframe, and ensure data can be accurately analyzed
- NOTE: all routes were actual clearances given by KBOS ground
- NOTE: arrival messages given at 16, 14, 10, 8, 7, 5, 4k, roll-out, and taxi-in


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1350Z ATC UPLINK 1/2
(KBOS) STATUS
OPEN

EXPECT TAXI TO
RW 27
VIA
A.C.D
HOLD SHORT
RW 33L
--- CONTINUED ---
<LOAD LOG>

```



1419Z ATC UPLINK 1/2
(KBOS) STATUS OPEN

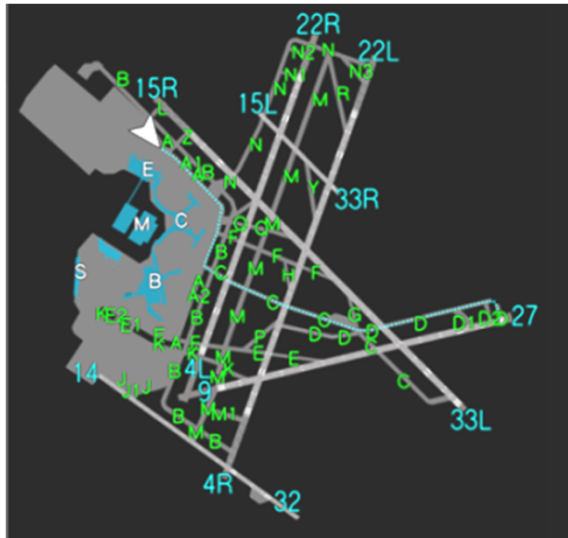
TAXI TO
RW 27
VIA
A.C.D.
HOLD SHORT
RW 33L
- - - CONTINUED - - -
<LOAD LOG>

1420Z ATC UPLINK 2/2
(KBOS)

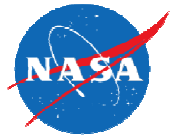
<STANDBY

<REJECT WILCO>

<PRINT REPORT>



Categories of Data Collected



Crew Performance

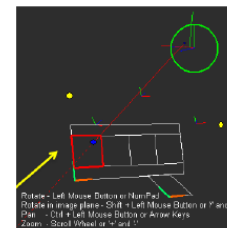
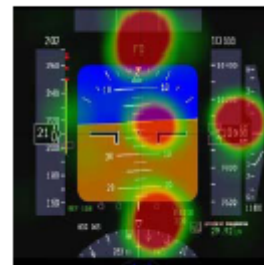
- Captain's Flight Technical Performance
- Crew Response Time
- Crew Head Position and Eye Tracking Data

Questionnaire Data

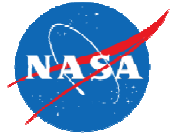
- Pilot Workload
- Situation Awareness
- Acceptability Ratings
- Pilot Debrief Comments

- **New Eye-Tracking capabilities**

- Installation of State-Of-the-Art eye-tracking system enables unique capability for quantitative assessment of human performance in high-fidelity simulation environments

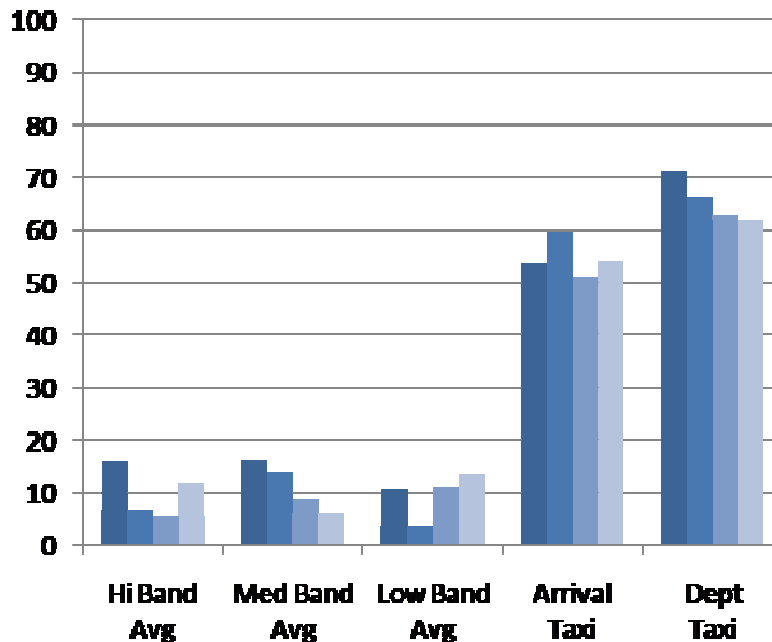


Crew Head and Eye Tracking Data

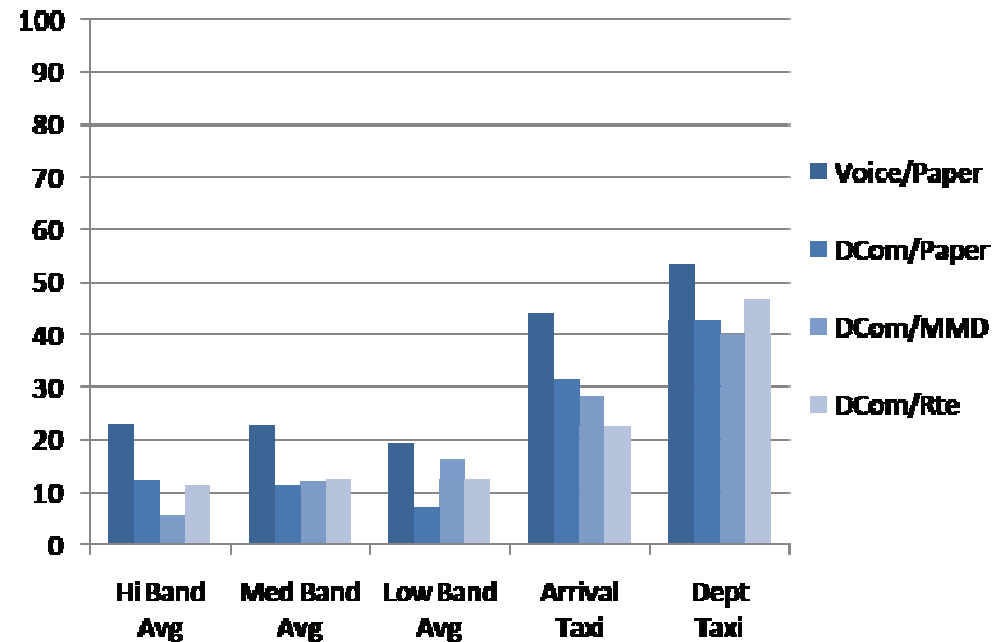


Comments: Pilot Flying (PF) inside cockpit more than Pilot Monitoring (PM) while airborne, more outside than PM while taxiing; data link appears to be a factor in scan pattern; more analysis pending

PF Head Up Time

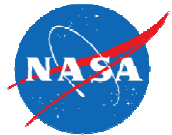


PM Head Up Time

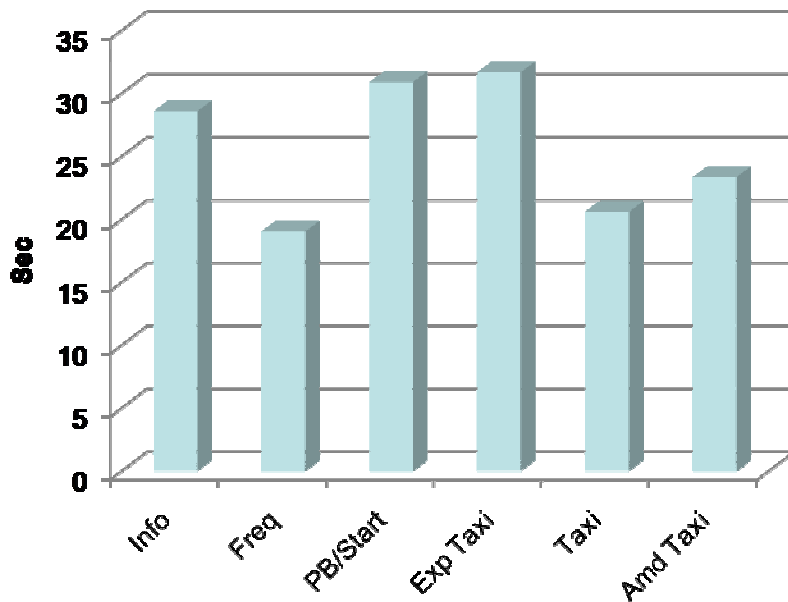


- PF (Pilot Flying, Captain), PM (Pilot Monitoring, First Officer)
- ARRIVALS: Hi (16 & 14k), Med (10 & 8k), Low Band (7 & 5K), <80 (taxi), DEPARTURES: Dep (taxi)
- Head Up defined as Eye gaze out the window, or Head pitch above the threshold (average Head pitch with Eye gaze out the window)

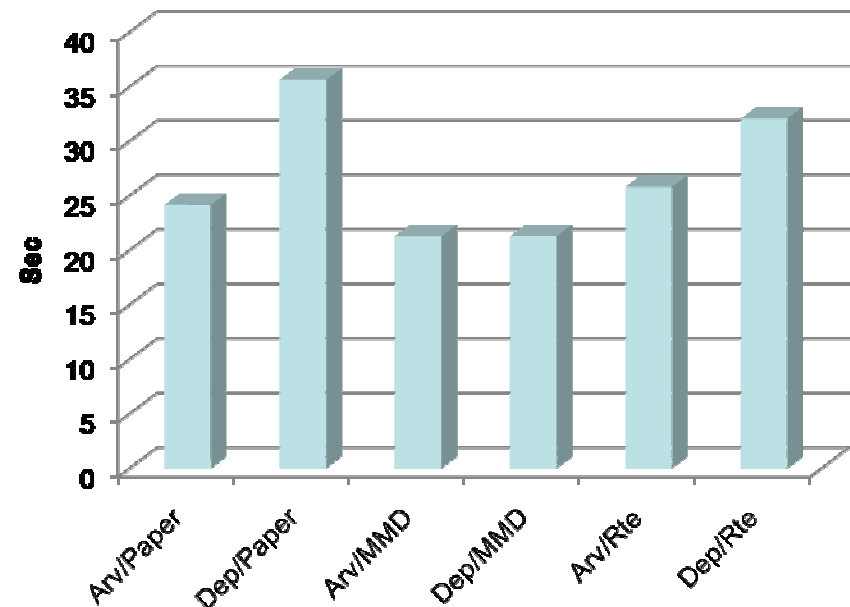
Crew's Response Time



Avg Response Time by Message Type

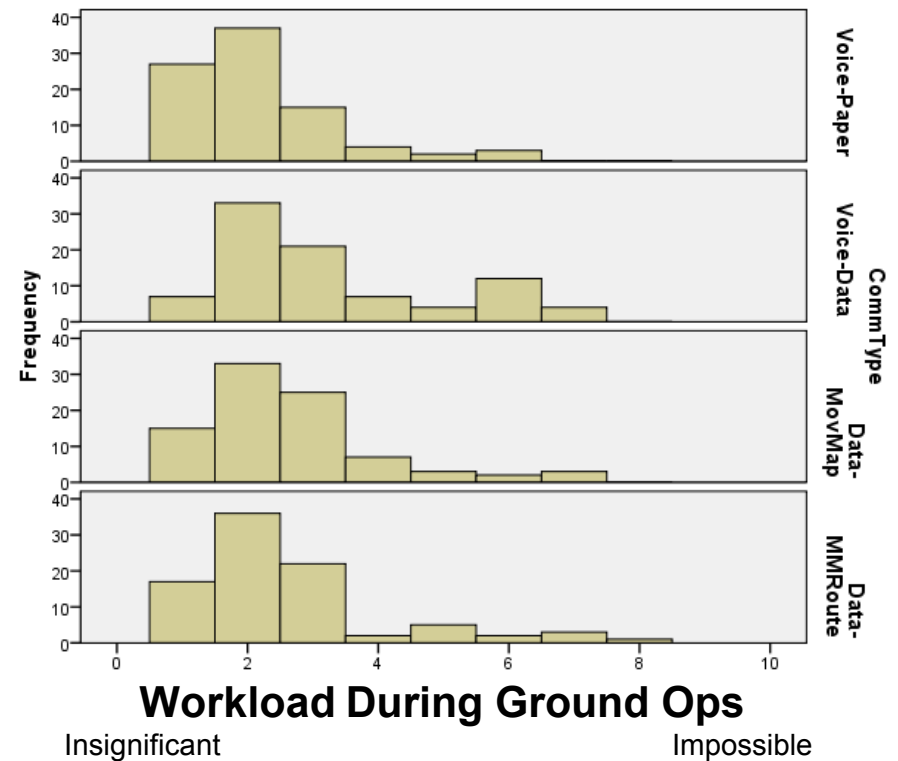
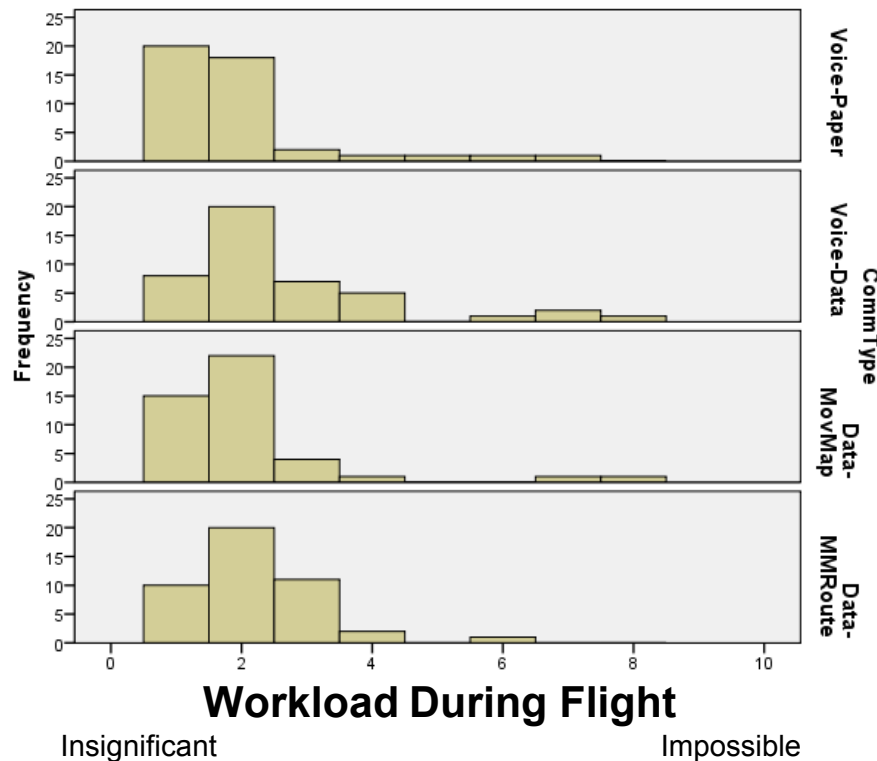
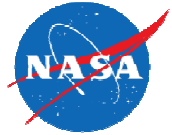


Avg Response Time by Modality



Comments: time from message sent (ATC chime) until either crewmember acknowledged on page two of CDU (90+% of the time it was the First Officer)

Workload: Flight versus Ground Ops

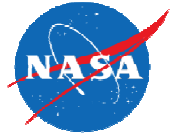


Ratings for 22 subject pilots with 16 scenarios per subject

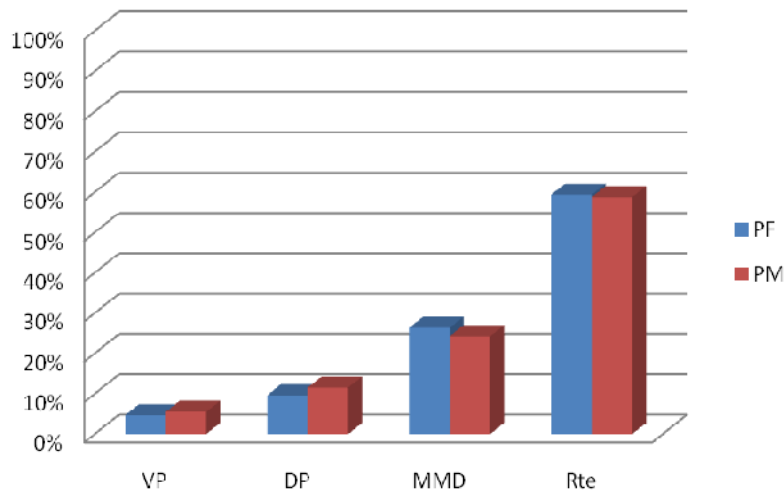
Y-Axis: Flight only in Arrival, Ground Ops in both Arrival and Departure (greater Y value)

Comment: Majority of responses were indicative of low workload (ratings of 1 to 3).

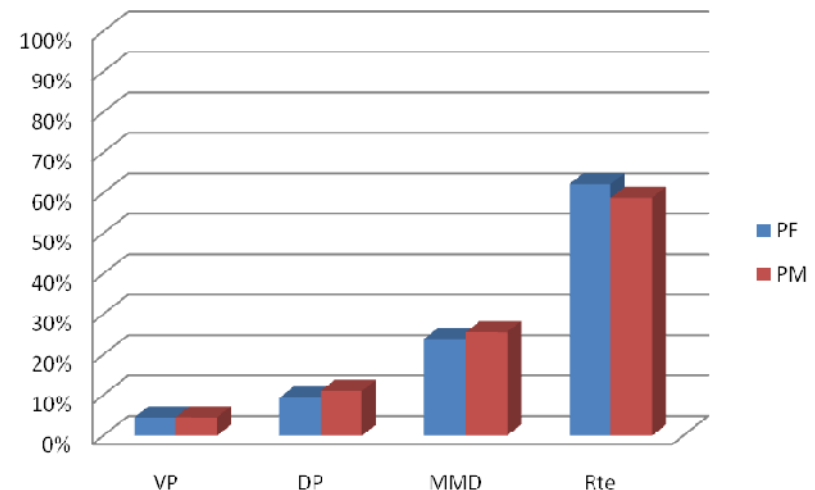
Display Preferences: Post Experiment Question



Display Preference by Crew Position
For Lowest Workload



Display Preference by Crew Position
For Highest Situation Awareness



VP = Voice w/ Paper Airport Diagram

DP = Data Comm w/ Paper Airport Diagram

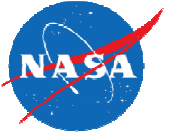
MMD = Data Comm w/ Moving Map Display

Rte = Data Comm w/ Moving Map + Route

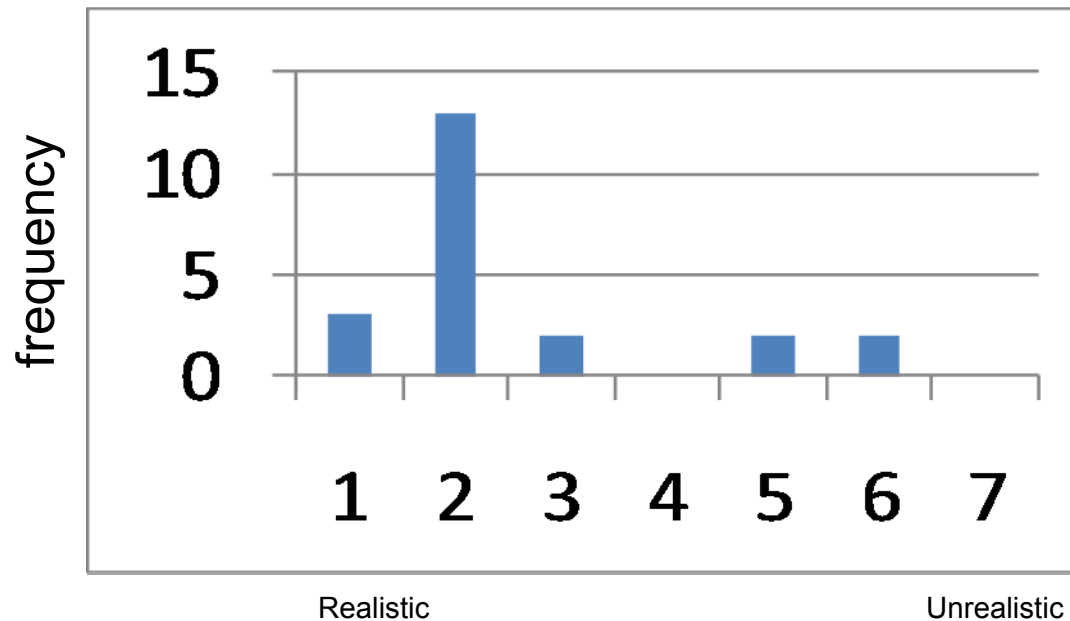
PF = pilot flying

PM = pilot monitoring

Acceptability – Post Experiment Question

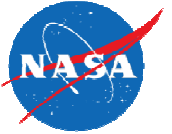


Response to Question: “What is your overall assessment of the potential of communicating clearance updates or changes using datalink while an aircraft is taxing or in a busy terminal airspace?”



Comment: Majority of pilots rated Data Comm in a Busy Terminal environment acceptable (Realistic) as portrayed in this study

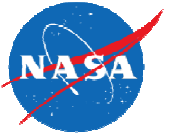
Pilot Debrief Comments



Overview: subjects stated Data Comm acceptable in operational, busy terminal area as flown in this experiment with the following caveats and suggestions:

- Expect the crew to require at least 1 minute to respond, 2 minutes preferable
- Above 18,000' Data Comm generally okay, somewhat less desirable 18,000 – 10,000
- Between 10,000' and FAF all Data Comm messages must be critical
- Never any Voice or Data Comm messages between FAF and clear of runway
 - Exception: may be acceptable to send "Taxi" message to aircraft during that time if no chime is used (responses varied from anytime, below 80 KIAS, to clear of runway)
- Most crews thought "Expected Taxi" message was useful
- Most crews thought "Pushback" and "Start" messages should be combined
- Most crews thought Downlink response should be on same page as Uplink message
- Need method to handle outdated messages and displays
- "Expected Taxi" message should include Hold Short instructions and red hold short bars
- Two different categories of Data Comm messages: important and informational (may require different crew response times, with / without an audible chime, etc)
- Issues with two messages in different mode to cross active runway (timing, priority, etc)
- Issues with requirement for Voice to start aircraft movement, especially with route on ND

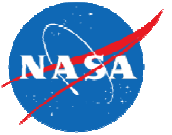
Potential Next Steps



Gaps

- ATC research facility linked to flight crew simulation
- Incorporate use of CDTI (TCAS and ADS-B "In") in the cockpit for more accurate equipage simulation and to offset party-line loss of situation awareness
- Conduct more complex NextGen type flight operations that require other CPDLC messages, such as trajectory reroutes and speed change messages
- Include Data Comm messages other than D-TAXI
- Off-nominal conditions (example: what happens when crew receives, understands, and is executing Data Comm message, but forgets to acknowledge the message)
- Connect Data Comm functionality with D-ATIS, to include graphical display of closed taxiways, construction, changes to runway length, etc
- Other traffic has ability to auto-taxi and self-space behind other aircraft
- Human voices for all party-line traffic calls

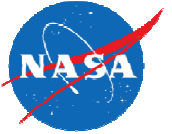
Products / Status



- Preliminary Final report sent to FAA in June 2010.
- Final Report sent to FAA (Levent Ileri), in July 2010.
Report title: *NASA / FAA Data Comm Airside Human-in-the-Loop Simulation*
- NASA Technical Paper based on Final Report is in progress
- Planned presentations:
Paper and presentation at the 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, TX (Sep 13-15, 2010)

Panel Session on Data Communications at the Annual Meeting of the Human Factors and Ergonomics Society, San Francisco, CA (Sep 28 – Oct 1, 2010)

Questions



Additional questions? Please contact:

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