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Display-Based Communications for Advanced Transport Aircraft

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SUMMARY

The next generation of civil transport aircraft will depend increasingly upon ground-air-ground and satellite data link for information critical to safe and efficient air transportation. This paper reviews previous studies which have examined the concept of display-based communications in addition to, or in lieu of, conventional voice transmissions. A full-mission flight simulation comparing voice and display-based communication modes in an advanced transport aircraft is also described. The results of this study indicate that a display-based mode of information transfer does not result in significantly increased aircrew workload, but does result in substantially increased message acknowledgment times when compared to conventional voice transmissions. User acceptance of the display-based communication system was generally high, replicating the findings of previous studies. However, most pilots tested expressed concern over the potential loss of information available from frequency monitoring which might result from the introduction of discrete address communications. Concern was expressed by some pilots for the reduced time available to search for conflicting traffic when they were using the communications display system. The implications of the findings for the design of display-based communications are discussed.

BACKGROUND

Each day thousands of scheduled air carrier operations occur within the National Airspace System (NAS). Communications vital to these operations are transmitted via radio from sites distributed across the country. The limitations in conventional radio transmissions as the primary medium of information transfer in the NAS are apparent by the large number of reports identifying air-ground information transfer problems to the Aviation Safety Reporting System (ASRS). Reviewing the reports of 1978-1980, Billings and Cheaney (1981) found that nearly three-fourths of the incidents involved some type of information-transfer problem (whether within the cockpit, among ground controllers, or between air and ground stations). Of the reports received in 1985 and 1986, one-fourth were a result of a failure in air-ground information transfer (Lee and Lozito, 1989). In both studies, most of these problems were the result of human error rather than equipment failure. The most common communication problems in air-ground communications were attributable to pilot misunderstandings of air traffic control (ATC) clearances or a failure to remember the message caused by preoccupation with other duties.

These findings are not surprising when it is understood that radio communications in dynamic environments rely heavily on the capability to rapidly process information and execute directives, often when the aircrew is preoccupied with other duties. As the airspace becomes more congested and as experience levels of aircrews decline, information-transfer errors attributable to limitations in information processing will become more common.

It is often argued that improved communications discipline and training will significantly reduce communication errors. However, decades of refining the language and procedures of air-ground communications have not resolved the problems inherent in the use of spoken language in the aviation environment. Not the least of these limitations is the propensity for the strict phraseology of communications to deteriorate under the highly routinized civil air transport environment. Violation of standard communications procedures can have tragic consequences. The worst aviation accident in history (at Tenerife in 1977) was the result of using nonstandard phraseology in a takeoff clearance exchange.

In the decade to come, the nation's airspace system will undergo significant changes in the means by which information is transferred between aircraft and ground stations. Increasingly, ground-air-ground information transfer will rely upon digital data link via satellite and ground-based radar sites (Mode S) and over VHF/FM station subcarriers. Some data link services are already provided by private industry (e.g., Airline Communication and Receiving System (ACARS)) and more services are slated for introduction as a part of the planned modernization of the ATC system. It is the eventual use of data link as the principal communications medium of the future that introduces the need to ensure that the system is designed to support the task of the human operator both on the ground and in the air.

Flight Deck Integration

The flight deck integration issues introduced by data link communications have been the focus of several studies both in the United States and abroad. One of the first studies to evaluate the use of data link for ATC services is reported by Diehl (1975). Using the then-current display technology, a comparison of various methods of information presentation was conducted. In a series of B-737 and DC-9 aircraft simulations, ATC message response times by test aircrews and aircrew ratings of device acceptability were measured. Response times to messages displayed visually, by synthetic voice, or by both, averaged about 7 sec. Response latencies to synthesized voice message averaged some 30% longer than either visual display alone or simultaneous visual/voice display. User acceptability was rated high, particularly for visual and print display of messages during high-workload flight phases, although some pilots disliked data link during ground-proximate operations (e.g., missed approach). No differences were found among the methods of presentations between the two- and three-crewmember simulations.

A more recent study by Uckerman and Radke (1983) examined the potential effect of airborne data link communications on the visual workload of Airbus A-300 transport aircrews. With the advent of two-person crews, there is concern that higher visual workload within the cockpit may increase the likelihood that potential conflicting traffic will not be sighted. An airborne terminal data link communications system, with its reliance on visual displays, may reduce external cockpit vigilance even further. The results of this study did not support the belief that the introduction of display-based communications (in this case a conventional Control Display Unit (CDU)) will adversely affect visual traffic scanning behavior during simulated approaches. This finding has been supported by others (Waller and Lohr, 1989). As with the earlier study by Diehl (1975), judged aircrew acceptability was generally high for the airborne terminal concept.

The possibility of using a display-based communications system for light, general-aviation aircraft was investigated by Parker and associates (Parker, Duffy, Christiansen, 1981; Parker and Duffy, 1982). Single-pilot, instrument flying is arguably the most demanding task in aviation. Particularly difficult in the high-workload environment of single-pilot instrument flight is the accurate retention and readback of ATC clearance information. Displaying such information could relieve much of the pilot's workload associated with retaining this information in memory or having to write it down while busy with other flight duties. In the studies by Parker et al. (1981), a display-based communications system with voice transmission as a backup was compared to conventional voice. The voice backup allowed the pilot to update weather and automated terminal information service (ATIS) data, and to clarify and confirm controller messages. No differences in subjectively rated workload were found for any phase of flight. As with previous studies, pilot acceptance of the data link communications concept was high. The provision of a voice backup was considered to be an improvement to display-based communications by the pilots and was generally perceived as an enhancement to safety.

Advanced Technology Aircraft

The potential benefits of data link technology used as a communications medium for ATC and advisory information, as well as for other types of information concerning weather and navigation, will not be realized unless it can be demonstrated that such technology will improve the process of air-ground information transfer when it is compared to the existing conventional voice system. There are two essential criteria by which the utility of a communications system can be measured. First, the speed at which information is transmitted, displayed, understood, and acknowledged (the information-transfer issue). Second, the ease and efficiency by which messages can be composed and transmitted by the user (the interface issue). The user, in this case the pilot, is unlikely to use a new communications system which either does not enhance the transfer of information or requires the use of a system interface which is difficult to use. Certainly it would be unacceptable to introduce systems which might delay communications, result in a net increase in workload, or result in reduced safety of operations.

Data link technology as a principal communications medium in cockpits will evolve at a time when the common crewmember size will be two (rather than three), and conventional analog instrumentation will be replaced by information displayed electronically. Furthermore, many tasks previously performed by crewmembers will be partially or fully automated. These changes to the context within which display-based communications occur require studies to be conducted which will approximate that operating environment. In order to investigate the potential effect of display-based communications in these future air transport cockpits, a full-mission, flight-simulation study was conducted in which a prototype data link communication system was compared to conventional voice communications for an advanced cockpit. While assessments of relative communication response times by pilots and measures of workload during flight-critical times were of particular interest, the study also provided an opportunity to observe and record aspects of pilot behavior which might affect other aspects of flight deck information management such as intracrew communications.

METHOD

Participants

Eight air-transport pilots currently flying scheduled air-carrier aircraft participated as paid volunteers in the study. Six of the pilots flew in the First Officer crew position and two flew as Captains at the time of the study. Flying experience ranged from 5,000 to more than 20,000 hr. For the purposes of this study, pilots served in the copilot (right seat) capacity as pilot-not-flying; the left seat (Captain's) position was occupied by an experienced airline pilot who carried out the normal duties of pilot flying. This pilot was employed as a simulator manager at the facility.

Apparatus

A generic, advanced, transport-aircraft flight simulator located at Ames Research Center was used for the study. A detailed description of the simulator may be found in Sexton (1983). The aircraft simulated is a medium-range, twin-turbojet civil transport of the mid 1990s. Instrumentation is provided on five color cathode ray tubes with primary control inputs provided by a side-arm, force feel control stick. The simulator has a fixed base with a single-channel, two-window visual attachment which provided the aircrew with a computer-generated, external visual scene.

For display-based communications, each pilot used a communications terminal located on a horizontal flight desk adjacent to the instrument panel. The terminal consisted of a 7 in. (horizontal) by 4 in. (vertical) electroluminescent display capable of generating 5 X 7 dot-matrix alphanumeric characters in a 40-character by 12-line configuration. All operator inputs were by touch points adjacent to message lines or characters. The pre-formed messages and menu architecture were adapted from prototypes developed by Boeing in 1987. The menu architecture is shown in appendix A. The main data link menu includes a selection for an ATC uplink page. This page was used to display ground-to-aircraft uplinks existing in the terminal's message buffer. Displayed ATC messages were verbatim transcripts, excluding call sign, of normal controller voice communications. Noncontrol information, such as weather alerts and ATIS, were also provided in verbatim form.

Air-ground transmissions such as clearance and weather requests could be initiated at any time by selecting the appropriate message request menu, selecting the desired message and touching the SEND message point located on each request page. An asterisk was displayed next to each selected message to provide the pilot with a confirmation of message selection. Where necessary, alphabetic and numeric characters could also be entered individually via touch points. These were used when entering location identifiers, altitude requests, etc. (appendix B).

In the conventional voice-transmission condition, both pilots wore headphones with an attached microphone and used push-to-talk microphone keys located on the aircraft control stick. In accordance with normal operating procedures, pilots were required to enter the appropriate communications frequency before transmission. This was also required for display-based communications, but only to provide a communications backup should the data link fail or an emergency occur. Also in accordance with standard procedures, pilots were instructed to acknowlege all transmissions, whether conventional or data link, as quickly as possible. Pilots were instructed to comply with ATC data link instructions as they would with conventional voice, e.g., in accordance with existing rules and regulations.

Alerting System

In conventional voice transmissions, each communication is prefaced by the appropriate aircraft call sign (or ground facility) to ensure that the information reaches its intended recipient. In data link transmissions, each aircraft is addressed discretely, making the use of call signs ostensibly superfluous. However, call signs also serve to alert the aircrew to impending communications, thereby generally enhancing the speed of information transfer. Data link transmissions, in contrast, will require an artificial means of alerting the crew that a message is in transit. For the present study, each uplinked message was preceded by a 3-Hz, flashing green light mounted on the glare shield in front of each crew position. In addition, a flashing "ATC UPLINK" message was displayed on the last line of the terminal display. The pilot was required to acknowledge the transmission by pressing the RECVD or UNABLE touch points on the terminal display. Either response would immediately extinguish the alert as well as notify the ground system that the message had been received. The alert would continue to flash until the pilot acknowledged the message. The controller monitoring the data link transmissions was made aware of when the message was acknowledged by the pilot as this downlink transmission appeared on the simulated ATC display.

Procedure

Each of the eight pilots evaluated both the conventional voice and the display-based communication systems while serving in the copilot crew position. The pilots flew both legs of a flight between Los Angeles International Airport (LAX) and San Francisco International Airport (SFO). One leg of this round-trip flight used conventional voice transmissions and the other leg used data link display-based communications. Origination (LAX or SFO) of the flight was counterbalanced across pilots, as was the order in which the two communications systems were evaluated.

Prior to the flight simulation test scenario, each pilot received a briefing on the proposed data link system. The system simulated in this study was comparable to the Mode-S system proposed by the FAA in ground-air-ground transmission time and in information-transmission rate. Each pilot was provided with part systems training on the use of the display-based communications terminal. Flight deck familiarization as well as full-mission training on data link system operation was provided before the test simulations. The simulation training was restricted to local flight in the SFO area, but included training in all phases of flight.

Test Scenario

With few exceptions, the test flight scenario replicated a scheduled air carrier flight between SFO and LAX. Standard instrument departures were used at both SFO and LAX. A profile descent was used for the SFO approach and a Standard Instrument Arrival was used for the approach into LAX. Details concerning the flight such as weather, runway assignments, etc., can be found in appendix C, which lists all ATC communications to the aircraft for both legs of the flight scenario. Communications to other air traffic were not simulated in the test scenario.

A few anomalies were introduced into the test scenario to compare pilot performance in operating the two communications systems under other than routine flight operations. In general, these operational anomalies also required the pilot to operate additional features of the communications terminal which would not normally be used. The following events were introduced for the SFO to LAX leg of the flight: (1) an incorrect altitude assignment which exceeded the aircraft's maximum performance ceiling, and (2) an en-route weather advisory issued for clear air turbulence within an altitude range which included the assigned flight level clearance. Both required pilot-initiated requests for new clearances. The LAX to SFO segment required the execution of a ground-initiated missed approach caused by a disabled aircraft on the SFO assigned runway. The missed approach required the aircraft to maintain a holding pattern at a nearby navigation fix for 10 min before being reissued an approach clearance.

Measurements of pilot performance were taken throughout the flight-simulation scenario. The two measures of central interest were the ratings of subjective workload and the time taken for the pilot to acknowledge transmissions from ATC. Workload ratings were administered by the experimenter following takeoff/departure and approach/landing phases. For the LAX to SFO leg, ratings were also requested following the missed approach. The ratings were taken in periods of low task activity as soon as practicable following flight phase completion to minimize interference of workload administration with ongoing cockpit activities.

The workload rating administered was a modified version of the NASA Task Load Index (TLX), details of which can be found in Hart and Shreveland (1987). Ratings for six workload dimensions are provided: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration Level. A bipolar rating scale for overall workload is provided. Definitions of the six workload dimensions are given in appendix D. Instructions in the use of the rating scales were provided before simulation training and testing.

Also of interest was the time taken for the pilot to acknowledge transmissions. For conventional voice transmissions, this is defined as the elapsed time between the end of the ground-air transmissions and the initiation of the pilot's verbal response. This time was calculated from tape recordings of cockpit voice transmissions. Acknowledgment of a data link communication in this study was measured from the onset of the communications uplink alert in the cockpit to the time the pilot keyed the appropriate response on the communications terminal. Some increase in acknowledgment time with terminal communications was anticipated because of the combined effects of limited operating experience and the additional time needed to visually locate and execute the appropriate terminal response.

Following simulation testing, pilots were provided the opportunity to discuss the advantages and disadvantages of the display-based communications system compared to the voice system now in use. Pilots were also specifically asked to identify any potential loss of information that may result from implementation of this communications system.

RESULTS AND DISCUSSION

Of central interest in the comparison of conventional voice communication and the data link system used in this study was the time taken to acknowledge transmissions and the change, if any, in pilot workload introduced by display-based communications technology.

Because of technical difficulties with recording equipment, only five of the eight pilots' acknowledgment times could be analyzed. Histograms reflecting the time needed to acknowledge ATC communications via data link for the five pilots from which data could be collected are shown in figure 1. The range of average response times across all flight phases was from 8 to 13 sec. This time, as noted earlier, is measured from the time the message alert is displayed to the time the pilot keys the ACKNOWLEDGE touch point on the data link terminal. By comparison, the average time to respond to conventional transmissions averages less than 2 sec.

The length of time to acknowledge communications via data link is of particular concern from the perspective of NAS system efficiency; flight deck design; and, ultimately, flight safety. Previous studies on data link communications also reveal slow acknowledgment times. In part, the slow response times in the present study can be attributed to the need for pilots to read the displayed message before acknowledgment. In the visual analog of conventional voice transmissions, the pilot has to read the message after it is delivered to the aircraft, whereas in voice communications the message is monitored aurally during the message transmission. Using an average adult reading speed of four words per sec (Carr, 1986), the average message reading time for in-flight messages (excluding ATIS) should have been about 2 sec. The remaining time used to acknowledge data link transmissions is attributable to other factors such as the time required to orient to the terminal display and, in some cases, time spent discussing the message content with the pilot flying (despite instructions to acknowledge transmissions as quickly as possible). These factors need to be examined more closely in subsequent studies, with the aim of significantly enhancing the efficiency of display-based communications with improved design and procedures.

A second objective of this study was to assess the effect of data link communications on pilot workload. Any new system introduced into the flight deck will eventually be evaluated in terms of increasing or decreasing crew workload. This is particularly true of aircraft certified for two crewmembers, as the certification assumes a level of workload that can be adequately handled by two pilots. Many design, training, and procedural factors combine to affect the workload imposed on the operator of a system. Certainly no single study can properly address the contribution of all of these factors to the workload imposed by a new communications system. However, in the belief that some indices of workload would reveal potential problem areas with the data link system implemented in this study, workload ratings for both conventional and data link communications were provided by each pilot. For this study the NASA TLX ratings were taken five times during the round-trip flight. One rating was taken for each of the two takeoff/climb phases, one for each of the two approach/landing phases, and one following the missed approach. Figure 2 shows the mean workload rating for each of the TLX categories (one category, Performance, is not shown). In virtually every category, workload ratings were slightly higher for display-based communications than for conventional voice. However, none of these differences between the two communications systems was found to be statistically reliable ($p > 0.05$). Whatever the impact of a data link communications system may be on other aspects of crew behavior, it did not significantly affect workload as measured by the TLX system. It should be noted, however, that the operations simulated in this study were relatively routine, with the exception of the missed approach and minor changes to clearances. Subsequent studies in more demanding operations are needed to fully assess the effects of data link operations on crew workload.

Following completion of the simulation, all pilots were asked to identify the advantages and disadvantages of the data link system and to suggest methods of improvement. Pilots cited the chief advantages of display-based communications as being the elimination of radio chatter and the ability to confirm instructions from the ground either by reference to the display or to the printout. The ability to make requests of the ATC system without having to wait for the frequency to clear was another advantage, as was the elimination of the need to memorize or manually record information. The commonly cited disadvantage of data link communications was the increased head-down time that such a system might require. This is of particular concern in the terminal area where reprogramming of Flight Management Computers is already causing concern among these and other pilots that too little time is spent looking outside the cockpit for other traffic. Of the eight pilots tested, five also voiced concern over the potential loss of traffic information resulting from data link communications. (Note that traffic was not simulated in this study). Pilots often monitor the communications frequency to locate other aircraft and their intentions as well as to assess the possibility of, and plan for, delays or reroutings that may occur. This "party line" effect of common monitoring of the same radio frequency is not possible with the discrete address communications of data link. In data link communications, a particular aircraft receives messages intended for it and not for any other aircraft. While discrete address has several advantages, e.g., eliminating the problem of inadvertently taking clearances intended for others, the loss of potentially vital, tactical information may be a serious disadvantage. Further investigation into the value of frequency monitoring, the effect of its loss on operational efficiency and safety, and the potential for replacing the lost information by some other means is needed.

Observations by the experimenter during the course of the simulation also revealed that other areas of flight deck integration will be affected by data link communications. Communication between crewmembers is one such area. The visual display of messages necessitates that one pilot verbalizes the contents to the other. This is needed even though messages are displayed for both positions, as the pilot flying will normally be attending to flight-path-management activities. This contrasts with conventional voice communications which permit frequency monitoring by all crew members. Verbalization of the message tended to increase the frequency and extent of conversation about the message content over what was observed with conventional voice transmissions. Data link communications, even with the addition of digitized voice for some messages, will probably increase internal cockpit communications to some degree, with as-yet-unknown consequences.

Less obvious in the evaluation of data link communications is the impact of replacing human-to-human communication with that of human-to-machine. The nonverbal elements of normal human communication, such as pacing and intonation, may convey confidence, a sense of urgency, and other information which is not generally available in display-based communications. This may result in the tendency for some individuals in this study to question clearances delivered via data link, and to delay acknowledgments to the "machine" to a greater extent than to conventional communications. In general, data link communications did not appear to elicit the same degree of attentiveness and promptness from the pilots as was compelled by voice communication in the present study. Although this is a subjective assessment on the part of the investigator, a similar observation has been noted by others (Hinton and Lohr, 1988). It may also be noted that display-based communications, which function with preprogrammed messages or free text entry, are much less flexible than conventional communications. This makes it more difficult for users to clarify and confirm message content (Parker et al., 1981). Consideration should be given to providing adequate conventional transmission capacity for this purpose in future NAS plans.

CONCLUDING REMARKS

The display-based communications system evaluated in this study resulted in substantially increased message acknowledgment times by pilots to ATC communications when compared to conventional voice transmissions. Several factors contributed to the increased response times with data link communications. Even though pilots were instructed to acknowledge data link messages as rapidly as possible, time required to visually orient to and read messages necessarily increased acknowledgment times. Finally, there appeared to be a general tendency to respond to data link messages with less urgency than to conventional voice, even though pilots were instructed to treat data link communications as they would conventional transmissions. It is possible that this behavior stems from a general attitude toward machine communications as not having the same degree of importance as communications between humans (pilot and controller). Further research is needed to evaluate this hypothesis, as such an attitude would have a significant impact on the utility of data link communications.

Subjectively rated workload assessments of the two communications systems did not reveal statistically reliable differences. However, this finding may not be generalizable to all flight conditions (e.g., emergencies). Post-simulation debriefing revealed uniformly high pilot acceptance of the display-based communication concept. Reported advantages included the elimination of both radio chatter and the need to memorize or record messages. Cited disadvantages included the potential for increased head-down time and the loss of some situation awareness available from the monitoring of other aircraft communications.

A number of the interface problems identified in this study can and should be addressed with improved design. For example, reductions in acknowledgment time can be achieved with the use of digital voice technology for time-critical, control information; although care should be taken to avoid interference with other aural alerts (e.g., TCAS). Integration of data link information into primary and secondary cockpit displays will reduce the visual orientation time, and the development of data link display symbology will substantially reduce the reading time (and thus head-down time) required by alphanumeric text. However, these design changes will require integration with other existing flight deck systems such as ground-proximity warnings, traffic collision avoidance, etc. Information retrieval from ground-based data systems will also require a more efficient interface design than was provided in the present study. Particular attention toward simplying the information retrieval process by aircrews would substantially enhance the utility of data link communications, particularly for aircrew access to weather products.

A systematic effort is needed to identify and resolve the human-interface problems associated with data link communications before this system enters widespread use in the NAS. Principles of design for the integration of data link information systems into the flight deck of advanced aircraft, and into NAS operations in general, must be developed to ensure optimal ground-air-ground information transfer. A concerted effort to identify these issues is now in progress (Lee, Proc. FAA/NASA/Industry Workshop on Data Link Communications, Dec. 7-8, 1988, proposed NASA CP).

APPENDIX A

MENU ARCHITECTURE FOR DATA LINK COMMUNICATIONS SYSTEMS

- MODE-S DATA LINK MENU
  - ATC UPLINKS PENDING
    - UNABLE
      - UNSAFE RADAR ECHOES NEAR BY
      - UNSAFE ICING THAT LOCATION
      - REQUIRED PERFORMANCE NOT AVAILABLE
      - CLEARANCE NOT CONSISTENT
    - RECVD
    - MODE-S
  - CLEARANCE REQUEST
    - PUSHBACK
    - TAXI
    - INITIAL ROUTING
    - ALTITUDE REQUEST
      - REQUEST TO FLY LEVEL ###
      - REQUEST TEMP FLIGHT LEVEL ###
      - WILL ADVISE
      - SEND
    - HEADING REQUEST
      - REQUEST TO FLY HEADING ###
      - REQUEST TEMP HEADING ###
      - WILL ADVISE
      - SEND
    - SPEED REQUEST
      - REQUEST TO FLY AIRSPEED OF ###
      - REQUEST TEMP AIRSPEED OF ###
      - WILL ADVISE
      - SEND
    - MODIFY FLIGHT PLAN ROUTE
    - MAKING MISSED APPROACH
      - PUBLISHED PROCEDURE
      - RETURN FOR ANOTHER APPROACH
      - ENTER HOLD FOR ### MINUTES
    - SEND
  - WEATHER REQUESTS
    - SEQUENCE REPORTS
    - WINDS & TEMPS ALOFT
    - RAREPS
      - FULL REPORT
      - UPDATE
      - SEND
  - ATIS REQUESTS
    - FULL REPORT
    - UPDATE
    - SEND
  - PIREPS
  - FLT PLAN CHANGE

APPENDIX B

EXAMPLES OF DATA LINK COMMUNICATIONS DISPLAY PAGES

REQUEST FOR CLEARANCE

<> PUSHBACK

<> TAXI

<> INITIAL ROUTING

<> MODIFY FLIGHT PLAN

<> MAKE MISSED APROACH

<> SEND   <> MAIN

NEW ALTITUDE REQUEST

<> REQUEST TO FLY FL LEVEL XXX	<> 1	<> 2	<> 3
	<> 4	<> 5	<> 6
<> REQUEST TO FLY FL LEVEL XXX -WILL ADVISE-	<> 7	<> 8	<> 9
		<> 0	

<> SEND   <> CLR   <> BKSP   <> MAIN

APPENDIX C

GROUND-AIR DATA LINK MESSAGES

<u>SAN FRANCISCO INT'L TO LOS ANGELES INT'L</u>

MSGS NO.

5. SAN FRANCISCO INTL AIRPORT INFORMATION
KILO 2045 C.U.T. VIS 7 MILES. TEMP 60 DEWPOINT
51. WIND 270 AT 12. ALTIMETER 30.04.
ILS RWY 28 LEFT APPROACH IN USE
LANDING RWY 28 LEFT. DEPARTURES RWYS
28 LEFT AND 28 RIGHT.

10. CLEARED TO LOS ANGELES INTL AIRPORT
VIA PORTE FIVE DEPARTURE AVENAL TRANS,
AVENAL, FILLMORE 4 ARRIVAL, AVENAL TRANS,
LOS ANGELES. MAINTAIN FL 230. SQUAWK
7401 ON DEPARTURE.

20. TAXI TO RUNWAY 28 LEFT

22. CLEARED FOR TAKEOFF RUNWAY 28 LEFT

24. SFO DEPARTURE 124.4

26. OAK CENTER 128.35

28. OAK CENTER 135.55

30. CLIMB TO AND MAINTAIN FL 490

32. CLIMB TO AND MAINTAIN FL 290

34. PROCEED DIRECT AVENAL

36. SFO WX ADVISORY. CLEAR AIR TURBULENCE
FL 250 THRU FL 300. SMOOTH ABOVE AND
BELOW.

38. CLIMB TO AND MAINTAIN FL 330.

40. LAX CENTER 135.30

42. CLEARED TO LAX VIA FIM4 ARRIVAL
DESCEND AT PILOTS DISCRETION
CROSS FIM AT 15,000 AND 250 KTS
LAX ALTIMETER 30.00.

44. LAX CENTER 135.5

47. ONTARIO INTL AIRPORT INFORMATION
WHISKEY. 25,000 THIN BROKEN
VIS 10 MILES. TEMP 68 DEWPOINT 60.

48. LAX APPROACH 124.5

52. DESCEND AND MAINTAIN 10,000

56. DEPART SMO HEADING 070
REDUCE SPEED TO 200 KTS
RADAR VECTORS FOR ILS 24 LEFT APPROACH.

60. DESCEND AND MAINTAIN 3,000

64. TURN RIGHT HEADING 210
66. DESCEND AND MAINTAIN 2,200
CLEARED FOR THE ILS RWY 24 LEFT

68. LAX TOWER 133.9

72. CLEARED TO LAND RWY 24 LEFT

76. TURN LEFT NEXT TAXIWAY
LAX GROUND 121.65

LOS ANGELES INT'L TO SAN FRANCISCO INT'L

MSGS NO.

80. TAXI TO 24 LEFT VIA UNIFORM AND 33-U
CLEARANCE AVAILABLE ON REQUEST.

805. LOS ANGELES INTL AIRPORT INFORMATION
OSCAR. VISIBILITY 3 MILES IN HAZE AND SMOKE
TEMP 61. DEWPOINT 54. WIND 270 AT 14.
ALTIMETER 30.10. ILS APPROACHES RWYS
24 LEFT AND 24 RIGHT. DEPARTURES RWYS 25 LEFT
AND 25 RIGHT.

810. CLEARED TO SAN FRANCISCO INTL AIRPORT
VIA GORMAN SIX DEPARTURE, AVENAL TRANS,
AVENAL DIRECT BIG SUR. BIG SUR PROFILE
DESCENT SAN FRANCISCO. MAINTAIN 3,000.
EXPECT FL 300 10 MIN AFTER DEPARTURE.
SQUAWK 4701 ON DEPARTURE.
DEPARTURE FREQUENCY IS 125.2.

820. LAX GROUND 121.8

824. TAXI TO RWY 25 LEFT

828. LAX TOWER 118.9

832. CLEARED FOR TAKEOFF RWY 25 LEFT

836. LAX DEPARTURE 125.2

840. MAINTAIN HEADING 250
RADAR VECTORS FOR VTU

844. PROCEED DIRECT VENTURA
CLIMB AND MAINTAIN FL 230

848. LAX CENTER 135.5

852. EXPEDITE THROUGH FL 190

856. LAX CENTER 125.65

858. CLIMB TO FL 300

860. CLEARED TO SFO VIA BIG SUR PROFILE
DESCENT. DESCEND AT PILOTS DISCRETION.
MAINTAIN FL 230.

868. OAK CENTER 134.55

872. SAN JOSE INTL AIRPORT INFORMATION ALPHA
2245 C.U.T. CEILING MEASURED 600 OVC
VIS 5 MILES. TEMP 63 DEWPOINT 57.
WIND 210 AT 12. ALTIMETER 29.98.
APPROACH IN USE ILS RWY 30 LEFT
DEPARTURES 30 LEFT. CAUTION FOR A CRANE
1 MILE SOUTHWEST, 225 FT MSL.

874. SAN FRANCISCO INTL AIRPORT INFORMATION
MIKE. 2245 C.U.T. CEILING MEASURED 300 OVC
VIS 1 MILE IN FOG. TEMP 53 DEWPOINT 53
WIND 280 AT 5. ALTIMETER 29.94
ILS APPROACH RWYS 28 LEFT AND 28 RIGHT
DEPARTURES RWYS 28 LEFT AND 28 RIGHT

876. OAK CENTER 128.35

880. CROSS BIG SUR AT 18000
SFO ALTIMETER 30.15

888. BAY APPROACH 123.85

892. REDUCE SPEED TO 230 KTS

APPENDIX C (Concluded)

896. 10 MILES FROM OUTER MARKER
TURN LEFT HEADING 310
MAINTAIN 2000 UNTIL ESTABLISHED
ON LOCALIZER

914. DESCEND TO AND MAINTAIN 3000

918. TURN LEFT HEADING 310
INTERCEPT LOCALIZER FOR RWY 28 LEFT

922. CLEARED FOR ILS RWY 28 LEFT APPROACH

926. SFO TOWER 120.5

930. GO AROUND
DISABLED AIRCRAFT ON RUNWAY

932. MAINTAIN PRESENT HEADING
CLIMB AND MAINTAIN 3000
CONTACT BAY DEPARTURE ON 124.4

936. TURN LEFT HEADING 180
CLIMB TO AND MAINTAIN 4000

940. CLEARED TO WOODSIDE VOR VIA PRESENT
POSITION DIRECT. MAINTAIN 4000.
HOLD SOUTH OF WOODSIDE ON WOODSIDE 141
RADIAL LEFT TURNS. EXPECT APPROACH IN 1O MIN.

944. FLY HEADING 350 FOR VECTORS TO 28 LEFT FINAL APPROACH COURSE

948. 10 MILES FROM OUTER MARKER
TURN LEFT HEADING 310
MAINTAIN 2000 UNTIL ESTABLISHED
ON LOCALIZER

952. CLEARED FOR ILS RWY 28 LEFT APPROACH

956. SFO TOWER 120.5

960. CLEARED TO LAND RWY 28 LEFT

964. TURN LEFT NEXT TAXIWAY
SFO GROUND 121.8

APPENDIX D

WORKLOAD RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself) How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

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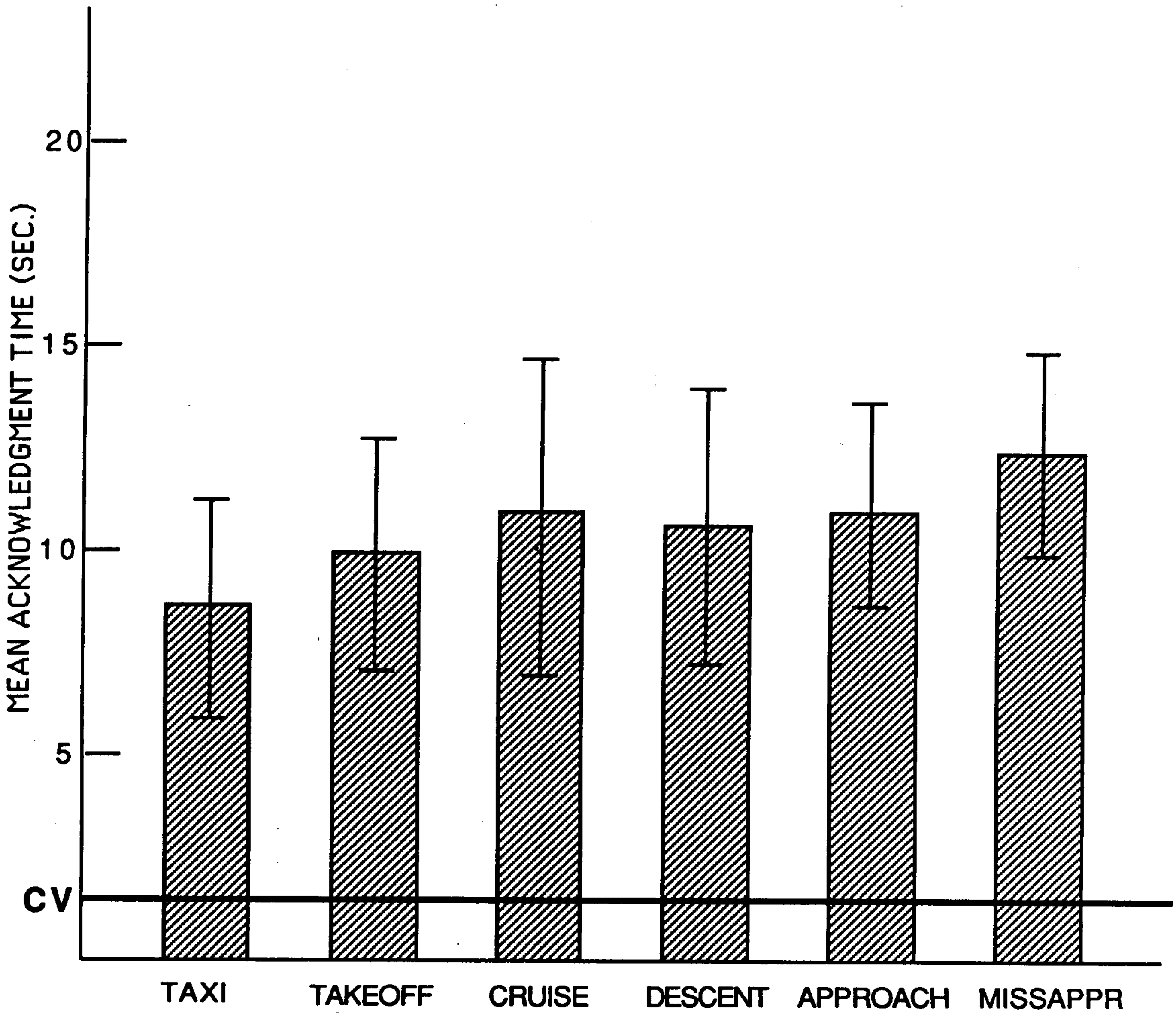

Figure 1.– Mean acknowledgment time to data link messages as a function of flight phase (N = 5; CV: Mean time to acknowledge conventional voice transmissions).

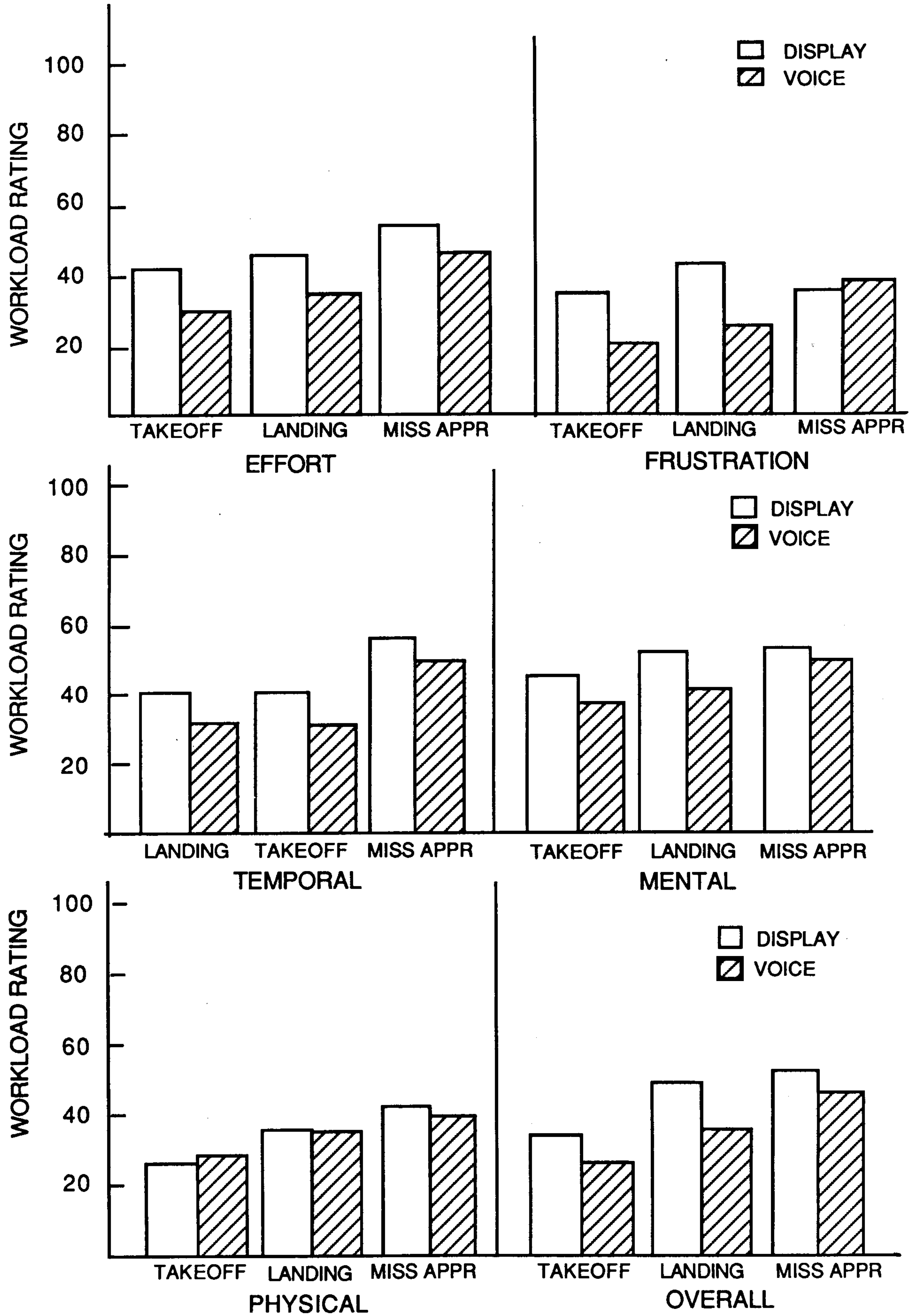

Figure 2.– Pilot workload ratings for voice and data link communications systems (N = 8 pilots).

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16. Abstract

The next generation of civil transport aircraft will depend increasingly upon ground-air-ground and satellite data link for information critical to safe and efficient air transportation. This paper reviews previous studies which have examined the concept of display-based communications in addition to, or in lieu of, conventional voice transmissions. A full-mission flight simulation comparing voice and display-based communication modes in an advanced transport aircraft is also described. The results of this study indicate that a display-based mode of information transfer does not result in significantly increased aircrew workload, but does result in substantially increased message acknowledgment times when compared to conventional voice transmissions. User acceptance of the display-based communication system was generally high, replicating the findings of previous studies. However, most pilots tested expressed concern over the potential loss of information available from frequency monitoring which might result from the introduction of discrete address communications. Concern was expressed by some pilots for the reduced time available to search for conflicting traffic when they were using the communications display system. The implications of the findings for the design of display-based communications are discussed.

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