An Assessment of Flight Crew Experiences with
FANS-1 Controller-Pilot Data Link Communication in the South Pacific

Nancy Smith, NASA Ames Research Center, nsmith@mail.arc.nasa.gov
John A. Brown, Boeing Air Traffic Management, john.a.brown@boeing.com
Peter Polson, University of Colorado, ppolson@psych.colorado.edu
John Moses, CadenceDesign Systems, Inc., jmoses@cadence.com

SUMMARY

This paper offers some "lessons learned" from a human factors evaluation of the Future Air Navigation System's (FANS) controller-pilot data link communication (CPDLC) function. Three airlines have been using FANS CPDLC since 1995, when air traffic facilities along South Pacific routes began providing data link communications services for FANS-equipped aircraft. The paper presents results from a survey distributed to Boeing 747-400 pilots with FANS CPDLC experience, and analysis of data link related reports submitted to NASA's Aviation Safety Reporting System (ASRS). Results suggest that many of the problems observed in the early phase of FANS CPDLC introduction were resolved or diminished as air and ground operators gained experience with the system. Other problems related to limitations in the initial system design still persist.

INTRODUCTION

FANS CPDLC

 The Future Air Navigation System, or FANS, is the first avionics system to support direct controller-pilot data link communication (CPDLC), including air traffic control (ATC) clearances, pilot requests, and position reporting. FANS CPDLC went on-line in 1995, with three international air carriers using the "FANS-1" equipment package for their Boeing 747-400 aircraft. Five air traffic service facilities that control the South Pacific en route airspace provided full CPDLC services to these aircraft, with two international data link companies supporting the data link communications of both airborne and ground-based systems. FANS CPDLC has been in continuous use in South Pacific oceanic airspace since 1995, and since 1998, on many routes elsewhere.

The air traffic service providers, data link service providers, operators, and aircraft and equipment manufacturers involved with the introduction of FANS in the South Pacific formed a working group known as the FANS Interoperability Team (FIT) to address technical and operational issues associated with FANS.

Since 1998, more aircraft have been certified for FANS CPDLC communications, including Boeing's 777, 757/767, 717, MD-10 and MD-90, and Airbus's A330/340, and more air and ground users are purchasing FANS CPDLC equipment. This fact, along with plans for introduction of CPDLC in the U.S. domestic environment, Europe and the North Atlantic highlights the importance of sharing lessons learned during the first few years of FANS use in the South Pacific.

Project Overview

Background

As part of several different research projects at NASA Ames Research Center we are exploring use of CPDLC in the domestic environment to exchange route information and clearances between the aircraft flight management system (FMS) and ground-based air traffic controller decision support tools (the Center TRACON Automation System, or CTAS). We felt that a human factors assessment of the experiences of FANS data link users would support our work and could contribute to other ongoing CPDLC development efforts (e.g., RTCA Special Committee 194). The assessment might also identify opportunities to improve FANS-1 CPDLC, and give new users of the system a chance to learn from the experiences of others.

We began with a search of the ASRS database for information on oceanic data link and found nine reports describing problems related to its use for ATC clearance communication. Five of these involved "Package A" data link, which, in contrast to FANS CPDLC, uses a radio operator as an intermediary to relay messages between pilot and controller. The other four involved use of FANS-1 CPDLC. Since available information describing operator experiences with CPDLC was so limited, our first goal was to gather more information.

Data Collection

In July 1998, the ASRS issued a request for pilots to submit reports describing any interesting incidents or events related to use of FANS-1 CPDLC, regardless of

the operational significance of the event. We were concerned, however, that this ASRS outreach might only elicit reports from pilots who either had problems to report, or who had strong feelings about the system. To get a broader sample of user experiences, we developed a fleet survey to complement the ASRS effort. The survey would reach a wider segment of the user population, and allow us to balance the detailed narrative descriptions of single events provided in incident reports with data characterizing the flight crew's experiences performing routine data link tasks. This survey was distributed to all Boeing 747-400 pilots who flew with the three major international carriers that were part of the FIT.

Usability Evaluation

A task description was developed for the set of pilot activities associated with normal operation of the FANS-1 CPDLC function. The task description was used as the basis for a cognitive walkthrough usability evaluation of FANS CPDLC. This evaluation provided a starting point for development of the 747-400 ATC Data Link Survey (Smith et al. 1999). Each project component—ASRS outreach, task analysis and survey—is described below.

ASRS INCIDENT REPORTS

The ASRS announcement of NASA's interest in receiving more FANS-1 related reports was released to Boeing 747-400 pilots in July 1998, and 18 more reports were filed in the six months that followed. Table 1 categorizes all 29 of the reports in the ASRS database filed by October 4, 2001 that referred to the use of data link for pilot-controller communication.

The most recent report included in this set was filed in June 1999. Absence of more recent reports might indicate that pilots flying for U.S. carriers have experienced fewer problems with FANS CPDLC in the last two years.

Conditional clearances. Altitude clearances that become effective at a future time or location (e.g., "at 120W," "at 1354z") are referred to as "conditional clearances." In four of the six conditional clearance reports in the ASRS database, pilots overlooked the "at" restriction on an altitude clearance and began climbing early. Several interface and procedural changes have been introduced to address this problem. These include adding "maintain FLxxx" to the clearance text proceeding the "at" restriction, and changing text formatting conventions used in flight deck presentation of uplink messages (Brown, 2000).

"Package A" vs. FANS-1 CPDLC. Eight of the filed ASRS reports describe incidents involving use of

Table 1. Summary of ASRS Incident Reports filed between August 1993 and September 2001 that refer to ATC data link.

Reported Incident Category*	FANS-1 CPDLC	Package A
Incidents involving use of ATC data link		
flight crew misunderstands conditional clearance	6	0
data link message is confusing	1	3
latitude or longitude coordinates misread	1	2
incorrect flight# entry; clearance sent to wrong a/c	1	1
crossing restriction violation	1	0
data link related workload problem	1	0
Other incident reports		
pilot comments about FANS-1 CPDLC	3	--
ATC data link unrelated to reported incident	4	2
duplicate reports (filed by other crew members)**	4	0

*Some reports fit more than one category.
**Duplicate reports are *not* included in other category counts.

Package A data link. Their presence demonstrates that controller-pilot data link problems are not unique to the 747-400 FANS implementation. In two incident categories, flight crews reported more incidents involving use of Package A. For a time, both applications existed on the same aircraft, which further complicated pilot use of one or both. Two ASRS reports describe use of Package A and FANS systems on the same route or during the same flight, and in one case the pilot suggested this was a contributing factor to the incident.

USABILITY ANALYSIS & SURVEY DESIGN

Task Analysis

A task analysis was done to develop a description of each routine task that a pilot might perform while using FANS-1 CPDLC in the 747-400. FANS-1 system documentation (Honeywell, 1996) and the South Pacific Operations Manual (1997) were used to complete the task descriptions. The analysis covered (1) preflight initialization; (2) tasks performed to establish or maintain a CPDLC connection (logging on, monitoring connection status, facility handoff monitoring); and (3) message exchange tasks (responding to ATC uplinks, sending ATC requests, sending ATC position reports).

These FANS-1 data link tasks on the 747-400 are performed using the flight management computer's multi-function control and display unit (MCDU) interface. Figure 1 shows three FANS-1 CPDLC MCDU pages.

```
   ATC LOGON STATUS          2105z ATC UPLINK 1/2        2105z ATC UPLINK 2/2
 LOGON TO        LOGON                       STATUS     /AT
□ KZAK        ACCEPTED □  □ <REQUEST           OPEN  □ □ 2200z                      □
 FLT NO                    PROCEED DIRECT TO             EXPECT CRUISE CLIMB TO
□ UAL1234              □  □ ALCOA                   □ □ FL350                      □
 ATC COMM      ACT CTR     /AT                         /REPORT REACHING
□ <SELECT OFF     KZAK □  □ ALCOA                   □ □ FL350                ARM> □
              NEXT CTR     CLIMB TO AND MAINTAIN
□                     □  □ FL310                   □ □ <STANDBY            LOAD> □
 ADS         ADS EMERG     /MAINTAIN
□ <SELECT OFF SELECT ON> □ □ .86                    □ □ <ACCEPT          REJECT> □
 ------------- DATA LINK    -------CONTINUED-------     ----------------------
□ <INDEX         READY □  □                    LOG> □ □ <PRINT              LOG> □
```
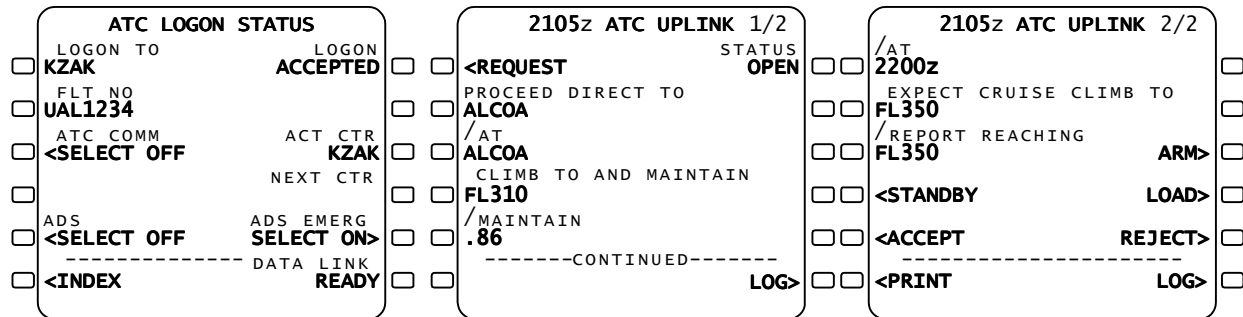
Figure 1. Examples of the 747-400's FANS-1 MCDU interface: ATC LOGON STATUS page
and ATC UPLINK pages for a 2 page uplink message.

Cockpit Cognitive Walkthrough

The task analysis described above was used as the basis for a cockpit cognitive walkthrough assessment of the support provided to pilots by the FANS-1 system interface. The cognitive walkthrough is a usability inspection method for interface design (Polson & Smith, 1999). System designers use this method to "walk through" a storyboard representation of the series of interface changes that precede and follow each action a pilot will take in performing a task, evaluating the adequacy of the interface in supporting correct performance at each step.

The walkthrough focuses on how interface labels, prompts and feedback can affect the pilot's performance of a task. This methodology works on the assumption that task performance in the cockpit can often be described as "performing by exploration"— a problem-solving process guided by knowledge of the task to be performed, of how to execute related tasks, and of the task's interface conventions.

The walkthrough formed the basis for the first draft of the survey that is the focus of this paper (Polson & Smith, 1999; Smith et al. 1999).

747-400 FANS ATC Data Link Survey

Figure 2 shows a few questions from the fleet survey that resulted directly from the walkthrough analysis of the subtask "detect uplink message." The arrival of a new ATC message on the flight deck is announced by a chime coupled with the text "ATC MESSAGE" presented on the EICAS display. These cues should prompt the flight crew to access the ATC UPLINK page in the MCDU. Prior research suggests that this may be an insufficient alerting mechanism for ATC uplinks (Lozito et al., 1993). The aural chime is not uniquely associated with an ATC uplink—it is also used as a SELCAL, cabin call and ACARS alert. Survey questions explore the adequacy of an alerting scheme that couples a non-specific aural chime with text on the EICAS display.

In addition to questions derived from the walkthrough, the survey addressed the following:

- What do pilots like about FANS-1 CPDLC?
- What do they dislike?

Detecting the FANS Clearance:

27. The aural chime announcement of a FANS ATC uplink message is:

> Clear ___:___:___:___:___ Confusing
> Adequate ___:___:___:___:___ Inadequate

28. Have you ever been on a flight when a FANS ATC uplink message was <u>not</u> detected as soon as it arrived?

__ Never   __ 1-2 times   __ 3-9 times   __ 10+ times   __ Don't know

29. If so, how was the message eventually noticed? _____

30. Which of the following creates the most difficulty in detecting an ATC message?

__ the chime is associated with other events besides the ATC message
__ the EICAS display does not reflect the number of open ATC messages
__ it isn't difficult
__ Other _____

Figure 2. Four questions from the FANS-1 CPDLC Fleet Survey that was distributed to Boeing 747-400 pilots.

- What elements of it do they use?
- How adequate are training and documentation?

The complete 12-page survey included about 65 task-related multiple-choice questions, 50 questions that used a 5-point rating scale, 8 narrative response questions, and several questions that asked pilots to compare different methods for ATC communication in oceanic airspace. It was distributed between 1998 and 1999 to all Boeing 747-400 pilots who worked for the three operators who used FANS on South Pacific routes.

SURVEY RESULTS

318 completed surveys were returned to us from the 1700 that were distributed to pilots. Since as many as 500 of those 1700 pilots had little or no FANS experience, the effective response rate is somewhere between 19% and 27%. Some demographic characteristics of the respondents are shown in Table 2.

Note that there is no control condition for most of the data collected in the survey. Most results consist of descriptive statistics and pilot comments. Limited between-group comparisons were used to assess the impact of training and experience on the pilots' answers to the 5-point scaled-response questions.

Results are grouped in the following categories: (1) responding to ATC uplink messages, (2) sending "downlink" messages to ATC, (3) availability of task-related information, (4) operational experience and training, and (5) pilot feedback about FANS-1 CPDLC. Presenting the complete survey results is beyond the scope of this paper; results on flight documentation, system usage statistics, phraseology and free text usage, logon, handoff and monitoring tasks are not fully covered.

Table 2: Demographic characteristics
of pilots who completed the survey.

Respondent Demographics			
curent position:	captain	first officer	other
(n=316)	32.0%	47.5%	20.6%
747-400 hours:	below 500	500-1000	over 1000
(n=315)	13.3%	24.8%	61.9%
prior "glass cockpit" experience:	yes	no	
(n=314)	52.5%	47.5%	
first used FANS in...	1996	1997	1998/9
(n=288)	54.2%	21.9%	24.0%
average number of FANS flights:	70	33	14

Responding to "ATC Uplink" Messages

Message detection and assessment

The first step when handling an ATC uplink message is to detect the message. The next step is to determine that this is a valid message—does the sender have the proper authority? Is the message current? Is it intended for my flight?

Several survey questions addressed representation on the flight deck of information used by the crew to detect the uplink message (the aural chime and EICAS message) and assess its validity. This includes information that is absent from the uplink message itself—identity of the message sender, time the message was sent, and callsign of the intended recipient.

The aural alert for ATC uplink messages. Survey questions 27-30 explore the adequacy of the ATC uplink message alerting scheme. Pilots were asked to rate its adequacy, and whether the alert had ever failed to call their attention to a new uplink message. Pilot responses are shown in Figure 3.

100 of 304 pilots (33%) rated the alerting mechanism "confusing" (4 or 5 on a scale of 1:clear to 5:confusing). 61 of 301 pilots (20%) rated it "inadequate" (4 or 5, scale of 1:adequate to 5:inadequate).

58 of 308 pilots (19%) reported that on at least one occasion they had failed to detect an ATC uplink message when it arrived on the flight deck. Most undetected ATC uplink messages were eventually noticed by pilots scanning the EICAS display; no adverse consequences were reported. Boeing's 777 FANS interface has a more salient presentation of ATC uplink messages, including an aural chime and complete, automatic presentation of most uplink messages on the large multi-function display (MFD) in the center of the instrument panel.

Information identifying message sender. The currently active air traffic service provider, or "active center," is the only possible source of ATC uplink messages. Active center is identified on the ATC LOGON STATUS page, but not on the ATC UPLINK page (Figure 1).

226 of 286 pilots (79%) rated information identifying the sending facility "important" (1 or 2 on a 5-point scale; 1:important to 5:unimportant).

70 of 286 pilots (25%) found its presentation "inadequate." (4 or 5 on a scale from 1:adequate to 5:inadequate).

61 of 293 pilots (21%) report "usually" or "always" checking sender ID on the LOGON STATUS page.
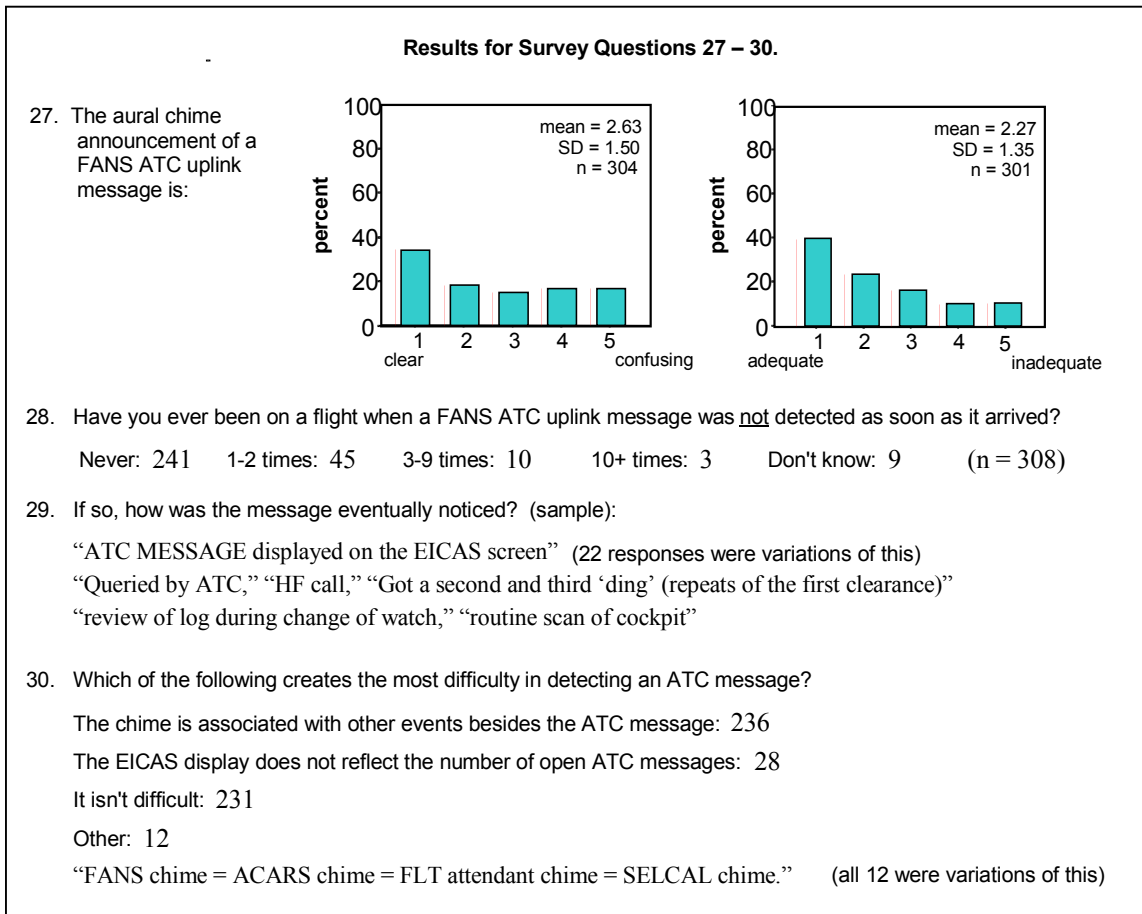
Results for Survey Questions 27 – 30.

27. The aural chime announcement of a FANS ATC uplink message is:

mean = 2.63
SD = 1.50
n = 304

clear 1 2 3 4 5 confusing

mean = 2.27
SD = 1.35
n = 301

adequate 1 2 3 4 5 inadequate

28. Have you ever been on a flight when a FANS ATC uplink message was <u>not</u> detected as soon as it arrived?

   Never: 241   1-2 times: 45   3-9 times: 10   10+ times: 3   Don't know: 9   (n = 308)

29. If so, how was the message eventually noticed? (sample):

   "ATC MESSAGE displayed on the EICAS screen" (22 responses were variations of this)
   "Queried by ATC," "HF call," "Got a second and third 'ding' (repeats of the first clearance)"
   "review of log during change of watch," "routine scan of cockpit"

30. Which of the following creates the most difficulty in detecting an ATC message?

   The chime is associated with other events besides the ATC message: 236

   The EICAS display does not reflect the number of open ATC messages: 28

   It isn't difficult: 231

   Other: 12

   "FANS chime = ACARS chime = FLT attendant chime = SELCAL chime."   (all 12 were variations of this)

Figure 3. Responses to the four survey questions about the adequacy of the aural chime announcing a new ATC message.

10 pilots reported receiving clearances from a non-controlling facility (so pilot concerns appear justified). All of the reported cases were detected by the flight crew. Pilot comments include: "within 15 minutes of changeover," "happened from FANS environment to voice controlled area."

<u>No identification of intended recipient in ATC uplink messages.</u> 20 pilots reported receiving a message intended for another flight. This was usually discovered (16 of 20 times) by the flight crew because the message's content didn't make sense; pilot comments: "it gave a waypoint we were not going to," "totally inappropriate clearance," "not relevant to our circumstances." The ID of the target aircraft for the ATC uplink is not part of the message, so it would be impossible for the crew (unless alerted by the controller) to realize the message was not intended for them as long as it seemed appropriate to their flight context.

<u>Message sequence information</u>. There are two issues here: (1) the order in which ATC uplink messages were sent by the controller to the flight deck, and (2) the relationship between a downlinked ATC request and an ATC uplink message that was received after the request was sent.

The time stamp in the title bar of the ATC UPLINK page (Figure 1) is provided by the flight deck avionics and indicates when the message was received, not when it was sent from the ground. It is technically possible (if improbable) for messages to reach the flight deck in a different order than they were sent. 174 out of 291 pilots (60%) report receiving uplink messages that seemed out of sequence.

If downlink requests are sent using a formatted message and the controller sends the appropriate formatted reply, the ATC UPLINK page will display a "<REQUEST" prompt next to the top left line select button, indicating that this uplink is a response to that specific request. Even when the appropriate formatted messages were used, however, there was some confusion. Some pilots complained that including "REQUEST" on the ATC UPLINK page was bewildering. Others were

uncertain how to interpret a reply that seemed irrelevant to their request, e.g., "When a clearance … is different from what was requested, i.e., REQUEST L10NM DUE WX. Response: CLEAR R10NM." "A response seemed inappropriate for our prior request." Overall, 153 of 295 pilots (52%) report having been uncertain on at least one occasion whether an ATC uplink was a response to a downlinked request.

Message comprehension

ASRS incident reports raised concerns about clearance presentation on the ATC UPLINK page, so the survey covered this topic in detail. Survey questions explored possible problems related to conditional clearances, use of non-standard phraseology, free text, long or multi-part clearances, multi-page clearances, representation of latitude/longitude coordinates, and MCDU page formatting.

Clearance presentation on ATC UPLINK page. 91 of 295 pilots (31%) said the presentation of FANS clearances on the ATC UPLINK page was "not always adequate." The reasons they gave included: uplink message presentation required two or more pages (29), use of non-standard phraseology or free text (17), message layout (13), conditional clearances (8), lack of important information—e.g., call sign, sending facility (7). Some pilot comments about uplink message presentation: "Incomplete text, not a normal ATC clearance." "When it continues over multiple pages." "Clearance should read as a complete sentence. Example: KZAK CLEARS XXX820 CLIMB TO MAINTAIN FL350 BY 1920Z. The elements are cleared authority, cleared aircraft, word clearance or report, action, limitations. Currently this information is not centrally located in one sentence."

Several multiple choice survey questions probed for operational problems related to message comprehension. Pilot responses are summarized below.

12 of the 128 pilots (9.5%) who received uplink clearances that included latitude and longitude coordinates reported that on at least one occasion those coordinates were misunderstood.

64 of the 304 pilots (21%) who had received conditional clearances reported misunderstanding a conditional clearance at least once.

62 of the 305 pilots (20%) who received "multiple element" clearances reported overlooking part of the clearance on at least one occasion.

189 of 306 pilots (62%) report switching from data link to voice (either HF radio or SATVOICE) to

resolve a question with ATC. 57 of those pilots had done this on three or more flights.

110 of 307 pilots (36%) report rejecting a clearance on at least one flight because its intent was unclear.

Read-aloud procedure. All three carriers trained message evaluation as a two-person procedure that involves reading the message aloud, either from the MCDU or from a printout. 96% of pilots felt their company's procedure was adequate for crew coordination and for understanding the clearance.

MCDU presentation of "loadable" uplink messages. Several types of FANS uplink clearances (e.g., route amendments) include elements that can be loaded directly into the aircraft's flight management computer (FMC). The cognitive walkthrough analysis suggested several potential problems for the flight crew when handling loadable clearances: overlooking the "LOAD>" prompt on the ATC Uplink page, understanding what will be loaded, and knowing where to review loaded elements of the clearance.

90 pilots reported receiving loadable messages from ATC. These included: 44 "DARP" (dynamic airborne route planning) route amendments, 26 "RTA" (required time of arrival), 24 "direct-to," 22 route offset, and 9 "other" clearances.

32 of the 90 pilots (36%) rated "Predicting what part of the uplink message will load" as moderately difficult or difficult (4 or 5 on a 5-point scale).

22 of the 90 pilots (24%) rated "Knowing where to review the loaded changes" as moderately difficult or difficult (4 or 5 on a 5-point scale).

Only 12 of the 90 (13%) gave "Detecting the LOAD> prompt" a rating of 4 (moderately difficult) on a 5-point scale (the average rating was 2.17). However, 20 of 90 pilots (22%) reported overlooking the LOAD> prompt on the ATC UPLINK page at least once. It's not clear how many similar kinds of oversights occur routinely on the flight deck and are caught and corrected without incident. This error rate seems noteworthy, however, since this type of clearance may continue to be infrequently used (and thus more error prone) and mishandling a loadable uplink could result in a clearance violation or loss of situation awareness.

Sending Messages to ATC

Three types of downlink messages were the subject of survey questions: replies to ATC uplinks, ATC requests, and position reports.

Composing a downlink message

Preparing the reply to an ATC uplink was rated a moderately easy task (average rating 2.2 on a 5-point scale; 1:easy to 5:difficult). ATC request preparation received an average rating of 1.8.

Position reporting was rated by pilots as the easiest of the three tasks with an average rating of 1.3. According to this survey, it is also FANS data link's most popular function: 91 pilots listed position reporting as their favorite thing about FANS.

Pilots did report two problems with the FANS-1 CPDLC position reporting function. Five pilots complained that they were unable to send a report when deviating more than 20 miles from the reporting fix (e.g., for weather). Nine pilots found it difficult to delete non-compulsory reporting waypoints.

Downlink message acknowledgment

The pilot sends a downlink message by selecting the SEND> function on the MCDU. The text "SEND>" changes immediately to "SENDING," then to "SENT" after the message receives a ground system acknowledgment. No feedback is provided about whether the controller has actually received or seen the message. This implementation follows a precedent from the voice environment, using a rule of exception: if the controller does *not* receive an expected response or position report, he will follow up by contacting the aircraft. Many pilots are dissatisfied with this, wanting the assurance of an acknowlegment that the message was received.

Pilots want feedback that the downlink message was seen by a controller. When asked if it was a problem that the system did not indicate whether a controller saw their downlinked reply to an ATC uplink message, 220 of 302 pilots (74%) said "yes." 180 of 316 (57%) also said it was a problem that there was no indication whether a controller saw downlinked position reports.

Controller response to "ATC request" downlinks

61 of 308 (20%) rated the ATC response time for *routine* requests "unacceptable" (4 or 5 on scale of 1:acceptable to 5:unacceptable).

96 of 289 pilots (33%) rated response time for *urgent* requests (e.g., weather deviations) "unacceptable." Examples of the 144 pilot comments about ATC response to weather deviation requests: "Frequently must use emergency authority to deviate." "…you are already well through the weather when the response comes through." "One example: 30 minutes."

It should be noted, however, that message response time in FANS CPDLC is demonstrably quicker than HF radio. Also, in answer to a later narrative response question, several pilots said that ATC response times had greatly improved over time.

Availability of Task-Related Information

In one ASRS incident report and one case described in the survey, pilots report that the NOTAM and chart had provided incorrect or misleading facility ID information. Several pilots have also reported trouble finding the 4-letter facility identifiers needed to log on to FANS CPDLC (see Figure 1). In response to the question, "Which tasks are difficult to remember?" one pilot replied: "When or where to sign on. Where to find various 4 letter sign-on codes. What portions of the planet use FANS and which do not." Other pilot comments include: "No positive log on ID on the Jepp Charts: put them on the charts." "Who has it? Who's using it? What's their identifier?"

As indicated by these two comments, pilots also found it difficult to track day-to-day availability of the system: what operations are supported, at what times, by which facilities.

Usability evaluations like the cognitive walkthrough can flag these task critical pieces of information. Notices to airmen (NOTAMs), flight documentation and other sources of this kind of information could be considered part of an extended system interface. Air carriers and air traffic service providers must insure that these documents are current, accurate, complete and available. This is particularly important during the early phase of system introduction or when a new air traffic facility comes on line, when frequent variations in supported services may be common.

Training and Operational Experience

Flight crew training

Pilot feedback. Evaluating the training provided by three international carriers for FANS-1 CPDLC was well beyond scope of this project. Pilots were asked to comment on their training, however, with the survey questions, "How well did your training prepare you for using FANS ATC data link? How could training be improved?"

141 of the 235 pilots (60%) who responded to this question said their training was adequate to excellent. Most pilots felt that "hands on" experience was essential for learning to use FANS-1 data link, either in a simulator or on the job. Many pilots wanted more simulator training. Ten pilots said the delay between their FANS data link training and initial line experinece was a problem.

Impact of operational experience

A between-group comparison explored the effect of flight experience on pilot ratings of task difficulty, with responses grouped by the number of FANS data link flights each pilot had flown. The sample was divided into six groups: group 1: 1-5 flights, group 2: 6-10, group 3: 11-25, group 4: 26-50, group 5: 51-100, and group 6: over 100 FANS data link flights flown.

Results showed a progressive decrease in task difficulty ratings with increasing operational experience. This pattern was observed in ratings of log on, facility handoff monitoring, replying to ATC uplink messages, preparing an ATC request, and position reporting tasks.

Pilots reported that system performance improved over time. Their observations included improved log on success rate, fewer lost connections, fewer handoff problems, improved response time to requests, and more block altitude requests granted.

Pilot Feedback about FANS-1 CPDLC

Pilot ratings of FANS CPDLC were consistently positive. When pilots were asked to rate different elements of the system (interface, documentation, task difficulty, information quality, response time, etc.) on a 5-point scale, with "1" indicating a positive response ("easy," "clear," "adequate") and "5" a negative response ("difficult," "confusing," "inadequate"), the average response to each question was between 1.31 and 3.11.

Table 3 summarizes responses to two questions that asked pilots to describe the main benefits and problems with FANS-1 CPDLC. Perhaps the strongest message here is that pilots like the system; in fact, many pilots chief complaint was that it isn't used enough.

Most of these pilots were simply stating that they wanted to see FANS CPDLC used more widely. "All facilities need to be using FANS" "not enough usage worldwide" "cannot use it every place we fly." But 8 pilots were also making the point that using different communication methods in different areas is a problem. "Not enough areas covered by FANS so switching to areas covered or not covered can be confusing." "Not enough facilities use it. Wider coverage and uniformity needed." "Lack of coverage areas, therefore too many different procedures for different areas."

Acceptability of FANS Many pilots encountered some problems with FANS-1 CPDLC, but most did

Table 3: Most common responses to survey questions 100 and 101.

Response Content	# of pilots
100. What features of FANS data link do you like most?	
Ease of use; quick response time	110
Position reporting	91
Great improvement over HF radio	83
101. What are the main problems with FANS data link?	
Absence of downlink acknowledgment	50
Not used widely enough (see text)	45
Interface issues	30
Hardware/system component issues	28
Message response time	21
Log-on and handoff issues	19
Uplink message annunciation (chime)	10
Free text or uplink phraseology	9
Conditional clearances	7

not. We have no data to indicate what problems pilots routinely encounter using either HF or VHF radio for controller-pilot communication. We did ask pilots to compare three different methods of ATC communication in oceanic areas and indicate their preferred method—FANS data link, HF voice, or SATVOICE (satellite telephone)—for five situations (Figure 4).

FANS CPDLC was the pilots' overwhelming first choice for clearances, position reports, and clearance requests; 95% or more selected FANS over SATVOICE and HF radio. SATVOICE was the most frequent first choice for emergency communications and conducting a dialog. Interestingly, 20-25% of pilots picked FANS CPDLC as their *last* choice for these two types of communications, preferring HF voice. Pilots were not asked to explain their ratings.

DISCUSSION

Results from this project provided a large body of information about operator experiences with FANS-1 CPDLC, including ASRS narratives describing operational incidents (e.g., misunderstood data link clearances, clearances issued to the wrong aircraft); quantitative survey data that permits analysis of a range of operator interactions with the system; and pilot feedback describing what they perceive as the system's benefits and problems. From these data we compiled a list of human factors issues or "lessons learned" related to pilot experiences with FANS-1 CPDLC in the Pacific oceanic airspace.

94. Rank order your preferred mode of communicating with ATC – FANS ATC data link, HF radio, or SATVOICE – for each of the following communications *(indicate your first, second and third choice):*
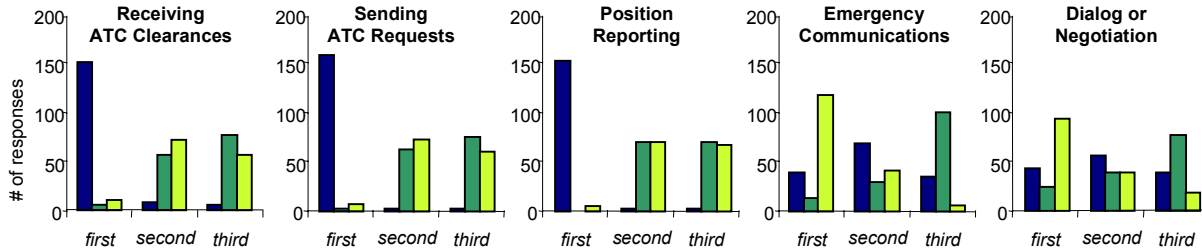
■ FANS-1 CPDLC
■ HF Voice
■ SATVOICE

Figure 4. Pilot ranking of their preferred communication method for 5 types of pilot-controller comunications.

747-400 FANS-1 "Lessons Learned"

1. interface problems

Missing or overly complex presentation of information represent key weaknesses in the original FANS-1 CPDLC interface. Specific examples include message alerting, clearance formatting, and information absent from the ATC UPLINK MCDU page (including sender ID, recipient ID and time sent). Each of these examples was linked to reported problems—misunderstood or overlooked clearances, clearances issued to the wrong aircraft—that could have had serious operational consequences.

Other problems with the FANS-1 interface are related to the complicated task interface in the MCDU. Problems related to this diminish, however, as pilots gain experience with the system. Most of these interface problems result from the decision to use the MCDU as the interface for FANS-1 CPDLC, which also limits their possible solutions.

2. importance of system status information

Pilots also need reliable access to accurate, complete, task-relevant information from sources *external* to the interface. This includes facility identifiers and up-to-date information about availability of services along the route of flight.

3. minimize inconsistencies—"global seamlessness"

Flight crew dependency on system status information is reduced as operations become more consistent across facilities. Minimizing inconsistencies in services, hours of operation, and procedures should be a goal of all system users and providers.

4. voice vs. data link differences

Standard phraseology and voice communication protocols are replaced in data link by standardized message sets and new interface conventions. Problems with conditional clearances, text format and request-clearance message pairs all illustrate that new problems are encountered with data link communication and new safeguards must be developed.

5. minimum system performance criteria

Human factors design guidelines exist for CPDLC systems (ICAO, 2000; RTCA, 2000), and usability evaluation methods like the cockpit cognitive walk-through can be used to find specific system interface problems (Polson & Smith, 1999). But there is often a cost associated with changing a design, and sometimes considerable cost with modifying a system after its operational introduction. How do you determine when a fielded system *must* be modified? Adding the intended recipient's callsign to ATC uplink messages, controller acknowledgment of flight deck downlinks, improved formatting of the 747-400's ATC UPLINK page are all improvements that could be made to the current system (in fact, a FANS-1 upgrade can be purchased that improves message formatting). Users and developers need to update system requirements as operational experience is gained, and need criteria for determining when costly upgrades are necessary.

6. importance of training & operational experience

Novice system users will be a continual presence as more ATS facilities begin adopting FANS CPDLC and more air carriers purchase FANS-equipped aircraft. Effective training and procedures for proper system use becomes increasingly important as the number and diversity of FANS users increases. A means for experienced carriers and ground operators to share training and procedures insights would benefit everyone.

7. new system introduction: expect problems

There are some general lessons to be learned from users' experiences during the introduction of FANS.

Problems with irregular service, inexperienced users, system failures, and the unexpected (e.g., conditional clearance violations) are likely with the introduction of any large new system. When that system is safety critical, like CPDLC, users must have a plan for detecting and resolving these problems quickly and efficiently. The FIT provides one example of how this can be done.

8. FIT-like cooperative response team

A coalition of operators, service providers, regulatory agencies, and manufacturers like the FIT has the resources and authority to fix problems as they occur. As experiences with FANS demonstrate, the need for this type of support structure may continue for at least several years after the system's initial introduction.

9. reporting mechanism

Systematic collection of pilot and operator feedback is critical for problem detection and understanding, and a confidential reporting system like the ASRS is invaluable. An international counterpart to ASRS would be ideal for gathering data about systems that affect multi-national operators and airspace. A more attainable goal might be a confidential reporting instrument that was system (e.g., CPDLC) specific. This should be wholeheartedly supported by the operator and regulatory community, and system users should be strongly encouraged to use it—ideally with immunity from regulatory action.

10. value & acceptability of CPDLC in this context

According to pilots, FANS CPDLC is a welcome improvement over other ATC communication methods used in oceanic and international operations. CPDLC will eventually provide similar benefits in other operational environments. The importance of close and responsive attention to user experiences during its expansion into new areas cannot be overemphasized.

CONCLUSIONS

Two kinds of system and interface problems were observed: transient problems for new operators that diminished with experience, and more enduring problems that are consequences of early design decisions. Results suggest that many problems observed in the early phase of FANS CPDLC introduction diminished as air and ground operators gained experience or developed procedural solutions. These include errors related to conditional clearances, confusion over message formatting or menu complexity, and ATC response time to flight crew requests. Some problems related to system design are

proving less tractable. Absence of controller acknowledgment to downlink messages, information absent from the ATC uplink, and the challenge of developing a CPDLC interface on the MCDU are some examples.

The FIT's experiences with FANS CPDLC demonstrate the value of a cooperative approach to the introduction of a system that has this broad a geographic and organizational extent. Continuing communication and cooperation among experienced and new users is needed to support CPDLC expansion into new operational environments.

REFERENCES

Brown, J. A. (2000). *Human Factors Issues in CPDLC.* The Boeing Company.

Honeywell, Inc. (1996). *Boeing 747-400 FANS flight management system pilot's guide.*

International Civil Aviation Organization (2000). *Human factors guidelines for air traffic management systems.* ICAO Doc. 9758-AN/966, Montreal, Quebec.

Lozito, S., A. McGann & K. Corker (1993). Data link air traffic control and flight deck environments: Experiment in flight crew performance. In *Proceedings of the Seventh International Symposium on Aviation Psychology*, Columbus, OH.

Polson, P. and N. Smith (1999). The cockpit cognitive walkthrough. In *Proceedings of the Tenth International Symposium on Aviation Psychology*, Columbus, OH.

RTCA, Inc. (2000). *Minimum human factors standards for air traffic services provided via data communications utilizing the ATN, builds I and IA.* RTCA/DO-256, Washington, DC.

Smith, N., J. Moses, P. Polson, S. Romahn, J. Brown, M. Dunbar, E. Palmer & S. Lozito (1999). A survey of flight crew experience with FANS-1 ATC datalink. In *Proceedings of the Tenth International Symposium on Aviation Psychology*, Columbus, OH.

South Pacific Operations Manual (1997). *Part 1: FANS (first step) CPDLC procedures.*

AUTHOR BIOGRAPHIES

John Brown is a Senior Analyst**,** Operations and Human Factors, with Boeing Air Traffic Management. His background includes British Royal Air Force operational pilot and graduate test pilot. In 1985 he emigrated to the USA to be Senior Test Pilot Instructor at the National Test Pilot School in Mojave, CA. After a 1988 move to Northwest Airlines, he worked as a simulator development test pilot and then manager of the Crew Resource Management training program. He has been with Boeing since 1996 and has been working on CPDLC interface design and related operational issues. His tasks include support of FANS Interoperability Teams in the Pacific.

John Moses is a Senior Usability Engineer with Cadence Design Systems, Inc in San Jose Ca. Prior to joining Cadence, he was employed as a Senior Human Factors Engineer at NASA Ames Research Center where his work focused on automation, training for automation, and interface evaluation (including both CPDLC and ADS-B). He received his Master's Degree in Human Factors and Ergonomics from the University of Miami in 1997 where his thesis focused on human error in maritime petroleum transfers. His background is maritime in nature and he retains a U.S. Coast Guard Master Mariner's license as well as Chief Engineer's unlimited horsepower license.

Peter Polson is professor of Psychology and a fellow of the Institute of Cognitive Science at University of Colorado at Boulder, where he has been a faculty member since 1970. During 1994-1995, he was a National Research Council Senior Research Associate in the Flight Management and Human Factors Division, NASA Ames Research Laboratory, Moffett Field, CA. He received his Ph.D. from the University of Indiana in 1967. Polson's current research concerns how information contained in displays supports skilled performance and guides learning by exploration. He is applying a theoretical model developed in collaboration with M. Kitajima in two task domains: office automation and flight automation.

Nancy Smith was hired by NASA as a research psychologist in the Human Factors Division after completing her Master's degree in Human Factors Engineering at San Jose State University in 1997. Her thesis was based on an experiment conducted in the Boeing 747-400 simulator at NASA Ames that explored the role of documentation in the operational introduction of new flight deck procedures. Her research interest is the selection and application of suitable methodologies for designing user-centered automation tools for the aviation community.