HUMAN FACTORS CONSIDERATIONS for LORAN-C RECEIVERS

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Abstract

Loran-C is an inexpensive, compact, and functionally powerful area navigation system. The application of this system to aeronautical navigation is an exciting occurrence for general aviation pilots. In the cockpit these systems simplify and increase the safety and precision of flight navigation by providing real time information on distance, bearing, and ground speed to pilot selectable navaids, airports, and air route intersections throughout the United States. Extensive data bases in these systems provide this information to pilots in response to a series of key presses and knob turns. Currently few receivers are certified for IFR flight, and none are currently certified for sole means of navigation under instrument flight rules. Used under VFR conditions or as backup systems to other navigation systems, the design of the display, control and logic of these systems is not as critical to flight safety as might otherwise be the case. When intended for use under the potentially unforgiving and often high workload conditions presented by instrument meteorological conditions, good human factors design is critical to safe operations.

This paper identifies current and potential human factors issues that are important in the design and operation of Loran-C receivers. The issues covered include display and control formatting, prompting for programming and function selection, error detection and correction, selection of emergency functions, warnings and alerts, cockpit location, and compatibility with air traffic control.

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Introduction

This paper presents a brief description of the flexibility and use of the aeronautical navigation system Loran-C. It also introduces selected human factors issues experienced by general aviation pilots using this system, and describes some research activities currently underway at the Research and Special Programs Administration's Transportation Systems Center of the U.S. Department of Transportation in Cambridge Massachusetts.

Description of Loran

Loran-C is a low frequency, ground reference navigation system which uses time synchronized pulsed signals from ground transmitting stations spaced several hundred miles apart for identifying geographical locations. Loran-C position is derived by measuring the difference in arrival time of pulses from a master and secondary transmitters.

The transmitters are capable of providing accurate information at distances up to 1,000 nautical miles from the receiver. The geometric relation of transmitters to one another determines the accuracy of position location. In areas of good coverage some studies have shown that receivers can calculate their geographic location to within 600 feet. Consecutive calculations provide the data necessary to determine such information as ground speed and track. The latitude and longitude of waypoints stored in the receiver provide the references necessary for the calculation of distance and bearing to a selected waypoint. When waypoint location is combined with ground speed information, times of arrival at the selected waypoints can also be calculated. When combined with altitude information from an outside source, some receivers can provide positive course guidance for vertical navigation.

Characteristics of Loran

Six characteristics of Loran system navigation systems contribute to their current popularity.

1. The low frequency Loran signal (90 to 110 kHz) follows the surface of the earth. Therefore the Loran signal has an advantage over higher frequency signal systems such as Very high frequency omni-directional range systems (VOR, 108 to 117.95 mHz) that are useful only for "line of sight" applications.

2. The Loran system does not require local navigational aids. Transmitters may be located as far as 1,000 nautical miles from the receiver and still be accurate.

(A VOR transmitter must be as close as 40 nautical miles to provide positional accuracy required for IFR flight at altitudes below 14,500 feet.)

3.The positional accuracy of Loran is independent of the distance of the receiver from the waypoint. (The sensitivity of a VOR receiver to lateral displacement off an airway decreases with distance from the transmitter. For example, at 30 nautical miles from the station one fifth of a full scale deflection of the course deviation indicator needle equals one mile. With time difference corrections, it's positional accuracy is accepted conservatively by the Government to be between 1/2 and 1/3 of a nautical mile.)

4. Loran systems are relatively inexpensive. Portable general purpose units that may be used in aircraft can be purchased for less than $350. Systems designed for installation in aircraft with user provided data bases may be purchased for as little as $1,000. Systems with an internal and updatable database of as many as 20,000 waypoints may be purchased for less than $4,000. (Comparable area navigation systems using VOR transmitters cost over three times that amount and have the accuracy and distance limits of VOR systems.)

5. The availability and decreasing cost of microprocessors provides our newest receivers with enormous computational power. There are several Loran receivers now available to the general aviation pilot that:

- Store and track flight plans with automatic sequencing from leg to leg
- Alert pilots to the presence of special use airspace
- Provide minimum safe altitude information throughout the National Airspace System (NAS)
- Provide graphic displays that show the aircraft's position relative to selected waypoints
- Contain Loran approach procedures at airports approved for their use
- Provide information on nearest airport upon request
- Provide integral calculators for trip planning while underway

6. Some Loran receivers are now being designed to integrate data from Loran and Global Positioning Systems (GPS). These systems have the potential for the vertical and horizontal accuracy required for precision approaches.

Loran Receiver Packaging

Today's aviation receivers have evolved from equipment originally designed for marine applications; an evolution that has produced a wide variety of control, display and logic configurations. This variety makes it unwise to generalize too specifically about the difficulty or ease of use of the equipment of different manufacturers from experiences gained from the use of only a few systems. However the sophistication of the aviation user and the demand for more and better features in a package that will fit in the limited space of personal aircraft have tended to result in receiver designs of increasing similarity. The design of today's receivers reflect a compromise between ease of use and compactness. In many cases controls, alerts and alphanumeric displays are squeezed onto a display panel that covers a surface area of no more than 12 to 18 square inches (77.4 to 116.1 sq.cm). The results are desirable and imaginative, but they do present challenges to the human operator who will always make errors, forget rules and procedures through disuse, and become disorganized under stress.

From the pilot's viewpoint, the Loran receiver is a computer with four major components. Each of these components is subject to variations in design, with respect to appearance, physical location, and function.

The digital electronic display may be made up of light emitting diodes (LED) or liquid crystal display (LCD) units . These displays present alphanumeric and sometimes graphic information to the pilot.

Most Loran receiver sets have between 5 and 30 push buttons. Sets with extensive databases may have as few as five buttons. However, receivers that depend on pilot data entry for their data bases include a key pack, therefore have more buttons.

Some sets, particularly those provided with databases, have at least two pairs of multi-function knobs. The outer ring of the knob may be turned to any one of a set of functions, e.g., "calculate" or "flight plan", or data categories such as "VOR" or "airports"; and the inner knob may be used to scroll through the contents of these categories.

All Loran receivers contain a microcomputer where speed calculations, bearing determinations and flight planning is accomplished. The functional power of the microcomputer is deployed through the use of control knobs and buttons, according to a set of procedures determined by the structure and logic of the computer. The pilot must memorize these procedures in order to utilize these capabilities efficiently in flight. It was observed in the laboratory that some of our operators tried to develop models of this structure to help them use the system, rather than relying on rote memory of the procedures. For example, one operator said that he saw the computer as a book and its various functions as individual chapters. Research is being conducted at NASA Langley to determine the influence of the operator's model on the types of errors that he makes.

Current Applications

VFR

Over 70,000 Loran sets are estimated to be in use today. These sets are used in search and rescue, by helicopter and fixed wing air taxis, in emergency medical services, by regional airlines, by corporate pilots, small charter operators companies, and in enormous numbers by private pilots. Loran is popular in these applications because it is an inexpensive area navigation system that allows pilots to fly direct to pilot defined waypoints as well as most facilities and intersections included in the national airspace system. With its distance measuring and other computational powers, it contributes greatly to flight planning, situational awareness, and therefore to flight safety.

IFR

A few manufacturers are making receivers that have been certified by the FAA for use in enroute and terminal use under IFR conditions. To date, none have been certified for use in instrument approaches. Perhaps the greatest driving force for Loran-C instrument approaches are state governments through the National Association of State Aviation Officials (NASAO). Many states have small cities that could benefit economically from regular air transportation to and from their small municipal airports. These municipalities cannot afford the cost of installing and maintaining expensive local navigational aids or they may be located in terrain that would interfere with the operation of such facilities. Loran, which is independent of local navigational aids and is usable in mountainous terrain could be used for instrument approaches into such areas.

The use of Loran for instrument approaches is being looked at cautiously. Current approaches are primarily designed and operated for purposes of evaluation and only exist at about 12 to 14 airports across the country. Loran signal monitors at each airport track the synchronized signals from the transmitters designated for each approach to determine if the signals meet accuracy requirements specified by the FAA. If an error is detected an alarm is sounded in the appropriate air traffic control facility and subsequent requests for Loran approaches will not be approved. Charts for the use of these approaches are not available to the general flying public and only specially certified aircraft may make the approaches under IFR conditions. The receiver and its installation must be certified. And, another certified instrument navigation system must exist in the airplane as a backup to the Loran. At the present time, Loran-C has not been approved for use as the sole means of navigation under IFR conditions.

Prominent human factors concerns in the use of Loran for instrument approaches include: crew workload, pilot error, and pilot awareness of system status. To reduce crew workload and the potential for pilot error during Loran approaches, time distance calibration data (from transmitter stations used in navigational computations for the approach), and the waypoints will have to be entered in the system prior to going into the approach mode. In addition, all Loran approaches must be flown with a crew of two. The earliest approved Loran approaches had to overlay another instrument approach, such as an ILS. This overlay redundancy is no longer required for approaches currently being approved, but other instrument approaches do have to be available to the runway. System status is monitored during the approach by the receiver and warning annunciations are presented to the pilot whenever system discrepancies occur.

The flexibility of Loran makes it possible to put instrument approaches into airports that otherwise might not support them. In some mountain locations a single microwave landing system (MLS) can be economically installed to provide a precision approach, but because of the mountainous terrain no VOR dependent systems can be used to bring the aircraft to the final approach fix or to provide guidance to the pilot for a missed approach. In some cases, obstacles may require the initial approach segment and departure courses to be curved. Research is underway to examine the utility of combining Loran with MLS for use at remote airports.

Human Factors Activities and Issues

As inexpensive Loran receivers become increasingly available, new applications for Loran are developed, and the use of Loran for navigation by a single pilot under instrument conditions becomes a reality, the need for information regarding pilot performance with Loran systems gains new importance. The Research and Special Programs Administration's Transportation Systems Center is initiating a series of research activities on human factors related to the use of Loran systems by private pilots. The research results will be available for use in developing realistic applications of Loran; criteria for Loran approaches, requirements for instrument training for Loran, and educational material regarding the use of Loran by private pilots.

Exploratory research has included the following activities:

- Comparison of Loran and VOR display and control panels
- Laboratory studies of operator's learning, programming, and exercising the various features of different Loran receivers
- Personal use of Loran during VFR conditions
- Flight tests of pilot tracking performance during non precision approaches
- Discussions and observation of the use of Loran by private pilots in personal aircraft

<u>Comparison</u>

Today Loran is the navigation system of choice among general aviation private pilots. Loran is fast replacing the VOR as an enroute navigation system. A comparison of Loran and VOR indicates that Loran, although a more powerful navigation system, has characteristics that may make it more difficult to use, more prone to operator error, and less error tolerant than the VOR. Recognition of these characteristics and their contribution to pilot workload and error will facilitate the identification, description and solution of human factors design problems that could contribute to a new family of errors among general aviation pilots if left unattended.

The frequency of a VOR is selected using knobs or thumbwheels dedicated to that function. These controls are located next to the windows that display the selected frequencies, and are used for no other purpose, and therefore they are rarely inappropriately used. Further, the controls are "detented" so frequencies may be selected without continuously monitoring the digit windows. This is big advantage to the single pilot who must watch for other traffic and maintain his heading and altitude while he tunes the VOR receiver. If an error in frequency designation is made, it can usually be corrected by one or two twists of the appropriate control.

A common method of selecting a waypoint with Loran is to turn the outer ring of a multi function knob to the detent marked VOR (VORs are commonly used as waypoints, particularly if the Loran is being used to fly published airways). The operator spells out the waypoint name using the inner knob as a cursor that presents letters consecutively on the display, and the outer knob to determine the location of the letter in the waypoint name. This process may take 20 or more discrete control actions, requires considerable head-down time, and is subject to a number of errors that are hard to detect. One common error is setting the function switch on APT (airport), rather than VOR. Since the APT and VOR are located at adjacent detents on a number of current receivers, VORs often have the same letter designations as airports that are located nearby. The adjacent location increases the likelihood of this kind of mistake and is a good example of DESIGN INDUCED ERROR.

Another example of design induced error is the adjacent location of the "waypoint" and "enter" buttons on another Loran set. These two buttons are used when entering flight plans into the set. In the flight plan entry mode "wpt" is pressed after each waypoint is entered into the flight plan, and "ent" is pressed after the final one is entered. If "ent" is pressed prematurely the flight plan will be closed out too early. As a result the plan will have to be edited. Inattention on the part of operator, or turbulence can easily cause the wrong button to be pressed and cause unnecessary workload to correct the resulting error. The design solutions to both problems are obvious and simple, increase the separation between the detents or buttons by inserting space, or other functions between them.

Verification of the correct selection of frequencies with a VOR is accomplished by looking at the digit windows that are dedicated to that purpose. If one digit in the frequency designation is incorrect, the solution is intuitive. The control beneath that window can be rotated through the correct number of detents to get to the correct digit. The operational status of the VOR is determined by pressing the button provided specifically for this purpose and listening for the morse code corresponding to the letter designation of the VOR.

Verification of the selection of the correct VOR waypoint with Loran usually is not done quite so easily. The distance to the waypoint may be checked for reasonableness. This distance, along with the bearing to the station, will probably be automatically shown on the Loran's electronic display. What is not always shown is whether a VOR or an airport has been selected. To make this determination an information page may have to be called up to see if the information is appropriate for the desired waypoint. Runway length data would indicate that an airport and not a VOR had been selected!

Standard verification procedures do not yet exist for Loran and should be developed as part of the training support provided for Loran users. The design solution to this problem would be to label the waypoint as it appears on the display as either a VOR or an airport. To correct the error the operator must delete the erroneous waypoint and completely reenter the correct one.

Selection of a waypoint by its three or four letter identifier assumes that this waypoint is stored in the data base of the receiver. This may be done manually by the owner or it may be provided as part of the receiver's data base. Only the most expensive receivers have this capability. The less expensive sets, and therefore those very often purchased by private pilots, have accommodations only for data bases that are manually entered by the user. Manual data entry requires time and the knowledge of what waypoints will be required in the upcoming flight, and has its own human factors problems.

Laboratory

This past year, we had several highly trained operators enter an eight waypoint flight plan into receivers provided by three different manufacturers. We also had the operators program a diversion by deleting two waypoints and adding three new ones. On average it took between six and seven minutes to enter the flight plan on the systems without a data base and about 2 1/2 minutes to do the same thing on receivers with a data base. When the operators were required to do the same thing while maintaining a desk top simulator in "straight and level" flight, it took approximately twice as long in each condition. If we had introduced "turbulence" into the simulator undoubtedly it would have taken longer. An aircraft flying at 120 kts will fly 24 miles in 12 minutes or make 4 turns around a holding pattern!

It took between two and three minutes to enter the diversion when not flying the simulator. The requirement to fly the simulator concurrently more than doubled this time. The time consuming nature of these activities was verified in our observations of a general aviation pilot's preparations for a Loran approach into a rather active airport in Massachusetts. These examples illustrate the potential dangers of data entry in the terminal area and the fact that doing the data entry on the ground is no guarantee that it will be done without error. In preparation for this demonstration flight, the pilot programmed the waypoints required for the approach while on the ground. While flying the initial segment of the approach, he discovered that the waypoints had been entered in the wrong order. Sitting behind the pilot, my associate noted that changing the sequence of the waypoints required considerable knob twisting and button pushing and would have required more than one turn outside the initial approach fix to accomplish it safely. The loss of pilot vigilance outside cockpit and the spare attention necessary to effectively manage the aircraft during this process has clear safety implications.

The designers of man/machine systems recognize that the human operator will make errors. The more actions the operator must make the higher the likelihood of an error. Manual data entry is an activity that is particularly error prone. Research at Douglas aircraft has shown error rates as high as 10% to be quite common even in the relative quiet of the laboratory. We too have demonstrated high error rates when manually entering latitude and longitude information into Loran systems. One approach to reducing the effects of operator error is to make the system ERROR TOLERANT. Systems may be considered error tolerant to the extent that they make it easy for the operator to identify errors that are made, make it easy for errors to be corrected, and reduce the influence of uncorrected errors on system operations. The VOR system is error tolerant to the extent that the frequency and radial selected for navigation is continuously displayed and so may be examined at any time for errors, and corrections can be made with the twist of a single knob. Once data are entered in a Loran system, they are no longer available for review unless specifically recalled. The only information continuously available on the electronic display may be the name that the pilot has assigned to the waypoint, and the distance and bearing to latitude and longitude coordinates that are now concealed in the system data base.

The analytic capabilities of current Loran systems indicate their considerable potential as error tolerant systems. One system that we examined would not accept latitude and longitude coordinates that were impossible. For example, any longitude or latitude designation in which more than 59 minutes were specified were rejected. Conceivably logic could also be developed that would reject VFR flight plans through prohibited airspace or alert the pilot to illogical waypoint sequences. For example, a waypoint that put an extreme course change in a route to the final destination could be flagged. Systems with map displays that graphically present the flight plan as it is programmed have been shown in advanced technology aircraft to provide a very effective means of detecting large programming errors. Such displays are now available for Loran systems.

The ease of correcting errors varies considerably from system to system. One system that we examined had an extensive data base and required less than four discrete actions to replace a waypoint. Systems requiring new lat/long insertions for waypoint corrections required about 25 discrete actions for such replacement. Given that pilots will make errors in data entry procedures, system features should be developed for detecting such errors, and once detected, errors should be correctable with a minimum of effort.

Clearly the smaller the system's data base is, the greater the data entry requirements will be while in flight. This will increase the workload of the flight, increase the probabilities of error and increase head-down time; all of which reduce flight safety. User entered data bases are also less likely to be current. The more sophisticated Loran systems are provided with data base updates at least every 56 days. Historically these periodic updates may contain as many as 1,000 changes. Pilots who use Loran without the advantage of these scheduled changes may neglect to update their own data entries and be using data bases with errors in them.

Today's receivers have great functional power. But, their functionality is embedded, or hidden from view. We call it EMBEDDED FUNCTIONALITY. If we can remember the correct procedures, we can get it to display our flight plan, tell us where the nearest airport is, tell us the frequency of approach control, and probably accomplish a variety of other functions depending on the particular receiver that we are fortunate enough have. Unfortunately, unlike the case with our simple VOR, whose functions are self evident, we can't tell how to access the functions in current aviation Lorans just by looking at them. We have to apply a set of rules and procedures that we memorize or that we can understand quickly from reference to a handbook. Either stress or just time away from the system reduces our ability to recall procedures or understand written material. Conversations with a number of private pilots who use Loran for VFR navigation indicate that through infrequent use they often forget how to access the capabilities of the Loran equipment in their airplanes. They use the systems to fly direct from one point to another but they have forgotten how to create new waypoints, to obtain frequency information for a particular airport, or to call up an airport, whose identifier they have forgotten, from their system's data base. This difficulty is particularly acute for pilots who rent and fly a variety of aircraft with different Loran equipment. Pilots who fly for small charter companies that obtain their equipment from a variety of sources may encounter the same problems. Important problem areas include: different procedures for accessing information required for certain emergencies, different sequences with which to enter latitude/longitude coordinates, and variation in terminology used for labeling controls and for prompting. These effects are made worse by the variations in format and information content of the quick reference handbooks that manufacturers supply with their systems.

Three potential solutions to this problem should be considered:

1. Certain safety critical functions should have dedicated controls. For example, perhaps there should be a button dedicated to obtaining information on the nearest airport. This is a safety critical function that should have quick access.

2. Prompting should be used more often. We found in the laboratory that as short a break from training as one week caused operators to forget how to accomplish certain tasks with the Loran. Often it was only the first step of a procedure that had to be provided for them to remember the procedures necessary to access the function that they wanted. Function selection controls could be used to select and activate the step-by-step prompting necessary to "walk" the pilot through the procedures necessary to implement the Loran functions required. Eventually, the growth in the importance, popularity and applications of Loran will result in the dedication of more cockpit space to Loran functions. This will permit the use of larger displays that can provide the pilot with the instructional detail necessary to identify and use the capabilities of Loran efficiently.

3. Limited standardization should be considered. Standardization is not always well received by American manufacturers. They often feel that the unique characteristics of their products make them more desirable to pilots and are a marketing advantage. Furthermore, poorly conceived standards could discourage innovation and serve to restrict the development of Loran technology. These are important points but need not preclude all efforts to standardization. Implementation of the following recommendations should not stifle innovation or interfere with marketing advantages, but should increase the usefulness of Loran systems and contribute to their popularity:

- The most safety-critical and error prone functions should be identified, and standard and simplified procedures for implementing those functions should be developed.

- A standard terminology for use in labeling and prompting should be developed.

- A standard format for quick reference handbooks should be developed.

Flight Test

All aeronautical Lorans have a course deviation indicator (CDI) to provide the pilot with a graphic indication of the lateral displacement of the aircraft with respect to the desired course to the next waypoint. This indicator may be a bar graph defined by light emitting diodes (LEDs) on the receiver's display or a round dial with a single needle like that used with a VOR that may be located remotely from the receiver. The sensitivity of this indicator is selectable on some receivers and may range from 2 1/2 miles (4 km) to the most sensitive setting of about 950 feet (289.5 m.) for a full scale deflection. A sensitivity of 1 and 1/4 mile (2 km) displacement off course for a full scale deflection is recommended by the Radio Technical Commission for Aeronautics (RTCA) for instrument approaches. The ideal sensitivity for instrument approaches is a matter of some controversy and is influenced by a number of variables, including whether the approach is to be manual or coupled. Since pilot tracking error (called flight technical error by procedure design specialists) accounts for over 80% of the .6 mile (with time difference updates) system error budget used by procedure specialists for designing instrument approaches, we examined the influence of CDI sensitivity on tracking error. A reduction in the flight technical error associated with Loran instrument approaches might make the system more useful for getting in and out of some of those remote airports.

We established a non-precision approach into a small uncontrolled airport and had 12 instrument rated private pilots make instrument approaches into the field using an instrumented single engine fixed gear aircraft equipped with Loran-C. The 12 pilots made a total of 144 approaches with the following six CDI sensitivities (displacements required for full scale deflections):

Crosstrack error and pilot workload for six CDI sensitivity levels

	RMS Error (Naut. miles)			
sensitivity	first 1/3	second 1/3	third 1/3	workload 1 to 7
2 1/2 miles(4 km.)	.26	.23	.17	2.4
1 1/4 miles(2 km.)	.15	.11	.08	3.2
3797 ft (1157 m.)	.15	.10	.09	3.1
1898 ft.(578.5 m.)	.10	.05	.05	4.0
949 ft.(289 m.)	.06	.04	.05	4.3
475 ft.(144.8 m.)	.06	.03	.0	5.6

The 475 foot sensitivity level is about the same as that of an ILS at the middle marker.

Each pilot was asked at three different points during the approach to rate (on a scale of 1 to 7) how he was working, with 7 indicating that the pilot had barely enough time to attend to all aspects of the flying task. As the sensitivity of the needle increased, cross track error decreased consistently. In fact increasing the sensitivity of the needle by four times over the 1 1/4 mile recommended by RTCA decreased the cross track error by over 30 percent during the first third of the approach, and nearly 40 percent during the last third of the approach. If 1,898 feet rather than 1 1/4 mile were used as the standard for CDI sensitivity, it could substantially reduce the system error value used in developing instrument approaches, and lead to a significant reduction in the width of the path required to be cleared of obstructions for Loran approaches.

This fourfold change also increased the pilot's estimate of workload by less than 1 point. The average workload rating of 5.6 that was given the highest sensitivity condition would not seem to be too unacceptable, but the 475 foot sensitivity level was rated as "unflyable" on 4 of the 24 approaches made with it. The second highest level produced a lower workload estimate, but was also judged uncomfortably difficult to fly on a couple of the approaches and might be too hard to fly under marginal flying conditions,for example, such as those that could be produced by icing.

Our next flight study will examine the flight technical error associated with using positive course guidance provided by Loran-C for straight and curved missed approaches.

Discussions

One of the most thorough and efficient methods of determining the human factors problems associated with a particular avionics system is to ask the users about the features of the system that they use and don't use, and the problems that they have with them. Prof. Wiener of the University of Miami has been very successful in using this approach, in conjunction with exhaustive cockpit observations, to identify human factors issues in the application of automation to air carrier flight decks. We have just initiated discussions with the Aircraft Owners and Pilots Association's (AOPA) Air Safety Foundation to conduct a survey of Loran-C use by private pilots. Our preliminary work in this regard has already revealed a few human factors issues beyond those already discussed.

The cockpit environment of the most common private aircraft may require special design considerations. There is often no room on the cockpit instrument panel within the pilot's area of primary view for a Loran receiver. The primary flight displays are directly in front of the left seat and the nav/com receivers are mounted in the center of the panel. Often the Loran receiver is mounted way on the left side of the panel nearly 45 degrees from the pilots primary line of sight. The pilot has to stretch and lean to the left to use the controls and read the display. Annunciations of warnings and alerts cannot be detected without looking directly at the display. Some pilots equip their aircraft with remote CDIs and warning annunciators located within their area of primary view, a requirement for IFR approved systems, but few VFR systems are so equipped. Deductibility of visual warnings is also reduced by high ambient illumination. Small GA aircraft often are designed for high outside visibility and may admit more light than is the case with larger aircraft. RTCA guidelines recommend that "...the brilliance of any display shall be adjustable to levels suitable for data interpretation under all cockpit ambient light conditions...," and many sets have either manual controls for this adjustment or sensors that automatically increase display brightness as ambient illumination increases. Unfortunately, the range of conditions seem to go beyond the limits of the display capabilities. Solutions to these problems include tilting the display/control panel toward the pilot, shielding the displays, and the use of auditory alarms.

Another RTCA operational standard is "minimum risk of inadvertent turn-off." Many of the small Piper aircraft have the switch for the electric fuel pump located next to the electronics master switch. The pump functions as a backup for the engine driven pump and is turned on for takeoff and approach and turned off when at a safe altitude. Occasionally when busy climbing out and heading toward the first departure fix the pilot will reach down, intending to turn off the electric fuel pump and inadvertently turn off the electronics master switch. The pilot almost instantaneously turns it back on. His VORs and communications are on line immediately, but his Loran is not. Loran guidance will be lost until the set reacquires the signal, the set is reinitialized, and the flight plan is called up again. It depends upon signal strength and some other variables. This could take over a couple of minutes to do and would create an uncomfortable situation if the aircraft were exiting a congested terminal area. The design of the Loran or requirements for its installation must preclude such inadvertent turn off.

Just as Loran must interface well with the aircraft that it is installed in, so must it be compatible with the practices of air traffic control. When flying under instrument conditions pilots must expect to receive unanticipated changes in routes of flight. When flying an area navigation system the changes may be given in terms of waypoints that are define in latitude and longitude coordinates. This information is given the pilot by the air traffic controller in the following format:

42.22.8 N and 71.29.4 E

In three of the sets that we examined in the laboratory, the hemispheric designator must be entered before the degree, minute and second information, for example:

N 42.22.8 and E 71.29.4

The difference between the order in which the alphanumerics are presented by ATC and the order in which they must be entered into the Loran sets may be expected to cause some errors in data entry, or rejected data entries that can be disruptive and time consuming.

Complacency is a term that aviation human factors professionals have come to associate with aircraft automation over the last decade. It describes a relaxed attitude associated with the confidence that flight crews develop in the reliability and correct functioning of the automated systems currently used to help fly commercial air carriers. In a sense it is a compliment to the designers, maintainers, and manufacturers of those systems, because complacency develops as an inverse function of the negative experiences accumulated by the system user and a lack of appreciation of the automated system's limits. The manifestations of complacency include relaxation in monitoring the performance of the systems and a willingness to let the skills replaced by automation decline. We now have good reason for adding LORAN COMPLACENCY to the lexicon of aviation terminology. Several examples of admitted pilot behavior justify this addition.

It is common today for pilots to connect their Lorans to the aircraft autopilot for VFR flights. This should free their attention for monitoring other traffic and for flight planning. Unfortunately, in some cases it also relieves the pilot of the necessity for monitoring his charts closely and gives him enough spare attention to engage in activities that reduce situational awareness and otherwise detract from flight safety. A recent discussion with the owner of a Loran-equipped Beachcraft Bonanza revealed that he accomplished considerable preparation for a presentation he had to make at his destination while under a Loran-automation controlled flight to a business meeting. The pilot did not know when he passed near restricted airspace or crossed a rather significant mountain range during the flight. He only returned to his flight duties when the Loran calculated ETA and distance information alerted him to the time when he had to prepare for the approach.

Private pilots also use their VFR Lorans for instrument approaches. They create instrument approaches into airports and "shoot" difficult instrument approaches with their Loran rather than the approved equipment, e.g. the ADF, and descend below minimums "for a better look" at home base airports. They do this because their experience with the apparent rifle-barrel accuracy of Loran gives them the confidence that they can perform these activities safely. They do not understand the limits of the Loran systems. For example, FVR Lorans are not designed to accommodate some of the waypoint configurations that may be created for a home made instrument approach. Closely spaced waypoints that require sharp turns may cause the sequencing mechanism to skip a leg of the programmed approach and will produce inaccurate time and distance estimations. Also, steeply banked turns, planned or inadvertent, may cause the receiver to momentarily lose the loran signal and skip a pulse cycle. Such cycle slips can indicate a lateral displacement of the aircraft by as much as a mile. The human factors problem of system misuse probably cannot be completely solved. However, I'm sure that if more pilots were aware of the limits of Loran, fewer pilots would be misusing it. User education would seem to be at least a partial solution here.

Conclusions

The issues concerning human factors of Loran-C are many. These issues illustrate that human factors is a "systems problem" that extends beyond the placement of knobs and dials on the Loran display and control panel, and encompasses the other aspects of the flight environment that are related its use. These issues include the following:

- Installation in the aircraft, including location and dependence on other aircraft systems
- Flight conditions under which the system will be used
- Interaction with air traffic control
- Experience of the pilot with the Loran receiver and with other similar systems

In order to identify human factors issues before they become safety issues, designers must review errors made in the design of similar systems, determine user requirements and anticipated equipment applications, and simulate the use of prototype designs in representative flight scenarios. Potential solutions to identified human factors problems include interface redesign, changes in procedures required to use the equipment, and user education.