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Pilot Evaluation of TCAS in the Long Ranger Helicopter

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16. Abstract

A specially modified version of the Traffic Alert and Collision Avoidance System (TCAS) was installed in a Bell Long Ranger helicopter in order to investigate the feasibility of TCAS operation in rotorcraft. This installation employed TCAS air-to-air surveillance to provide automated traffic advisories that were displayed in the cockpit on a color cathode ray tube display.

As part of this study, 12 subject pilots evaluated the utility of the installation through brief test flights in the vicinity of a major airport. Among the topics investigated were the rate of alarms, the computer logic for issuing advisories, the bearing accuracy, and the display symbology. Several recommendations for adapting TCAS to the rotorcraft environment resulted from the testing.

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1.0 INTRODUCTION

The Traffic Alert and Collision Avoidance System (TCAS) is a beacon-based airborne collision avoidance system that provides pilots with advisories to assist them in maintaining safe separation from transponder-equipped traffic in their vicinity. Several levels of TCAS capability are possible. TCAS I is a low-cost version that provides automated traffic advisories only. Minimum TCAS II adds vertical resolution advisories that suggest the vertical direction in which the equipped aircraft should maneuver in order to avoid a collision.

The prime thrust of TCAS development has been the development a system suitable for implementation in fixed-wing aircraft. However, it has been recognized that TCAS could be employed in rotorcraft as well, and the Federal Aviation Administration has initiated work to determine the design changes that would be required in moving from a fixed-wing to a rotorcraft environment.

There are several reasons why TCAS requires special modifications in moving from fixed-wing to rotorcraft. First, the operational environment is different. Vertical resolution advisories are less likely to be acceptable while visual separation techniques are more likely to be effective. This has led to a recommendation that a rotorcraft installation provide traffic advisories only (and not resolution advisories). In addition, the rotorcraft is not as well suited to air-to-air surveillance, primarily because there is typically no unobstructed location available on the airframe for mounting a bearing-measuring antenna. A principal issue is whether or not an antenna location can be found that produces acceptable bearing accuracy. Finally, the multipath interference problem is more severe for a low-flying rotorcraft than for an aircraft operating at higher altitudes.

As part of the investigation of the above issues, Lincoln Laboratory installed an experimental TCAS unit on a Bell Long Ranger helicopter and collected a considerable amount of in-flight data on surveillance performance. Results of this surveillance study are documented in Reference 1.

Although the surveillance study characterized TCAS performance from a technical point of view, the ultimate usefulness of the system could not be verified without obtaining data from pilots actually using the system in a realistic air traffic environment. Consequently, 12 subject pilots were asked to fly brief missions using the TCAS and to evaluate its utility. This report presents the results of these flights.

1.1 Aircraft and TCAS Installation

The aircraft employed in the flight test was a Bell Long Ranger helicopter equipped with a special TCAS antenna and test electronics. Figure 1.1 is a picture of the aircraft showing the TCAS antenna location employed. For typical fixed-wing installations, this antenna has a nominal RMS accuracy of approximately 8 degrees. However, the obstructions presented by the structure of the Long Ranger resulted in an increase in the RMS error

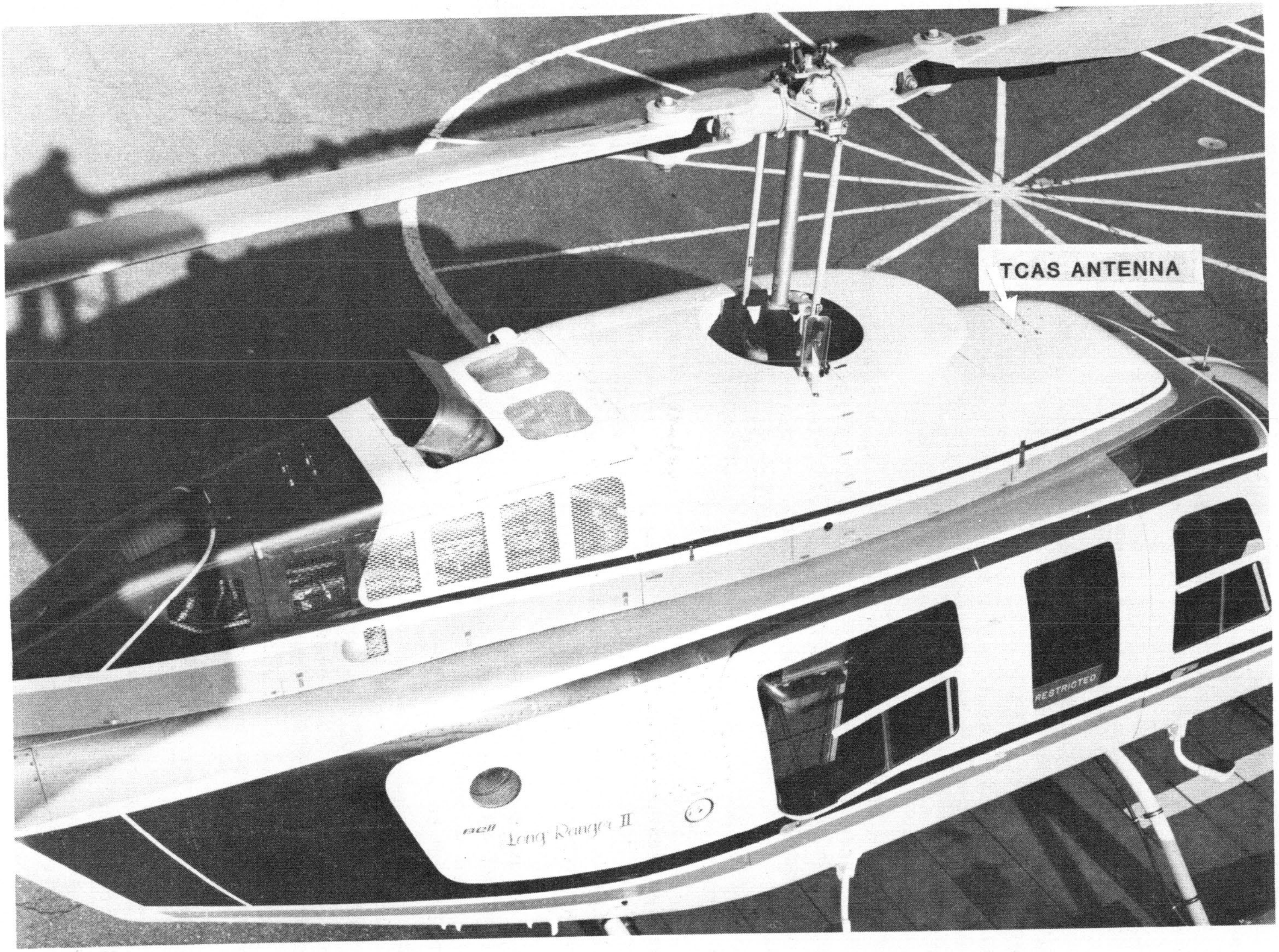

Fig.1.1 Bell Long Ranger helicopter and TCAS antenna

by a factor of two (see Ref. 1). The Long Ranger closely resembles the widely used Bell Jet Ranger and hence the antenna installation problems are similar to those of a large fraction of the helicopter fleet in the United States.

Figure 1.2 shows the TCAS traffic advisory display mounted in the Long Ranger cockpit. The display consisted of a Bendix IN-2027A color weather radar indicator operated as part of a special display unit known as the Airborne Intelligent Display (AID). This display unit was built at Lincoln Laboratory and used previously in TCAS testing in a Cessna 421 fixed-wing aircraft. The dimensions of the face of the indicator were 4.25 inches by 3.25 inches. The resolution was 256 pixels by 256 pixels. Alphanumeric characters were a maximum of 5 pixels in width and 14 pixels in height (approximately 0.08 by 0.17 inches). The display was mounted on a special bracket installed in the left-hand side of the cockpit. In an actual rotorcraft installation, it is likely that a lightweight, monochrome display would be employed and that it would be mounted on the center console. However, the information content of the AID display was identical to that anticipated for actual rotorcraft implementations and display characteristics peculiar to the experimental installation are not thought to have had any significant influence on test results.

Figure 1.3 shows the symbology of the CRT display. Own aircraft position was indicated by a chevron. A range ring with a radius of 2 nmi was drawn around this location. The horizontal positions of other aircraft were indicated by triangles. Each aircraft's altitude was indicated by an alphanumeric tag containing relative altitude in hundreds of feet (the aircraft at 1 o'clock in Fig. 1.3 is 600 feet below own aircraft). The altitude tags for aircraft that were not reporting altitude consisted of three question marks (see aircraft at 10 o'clock in Fig. 1.3). Two colors were used: white for background information and non-urgent targets, yellow for urgent targets (see section 1.2 for a description of the urgency criteria). When a yellow target first appeared, an alerting tone (800 Hertz frequency, one second duration) was sounded via the aircraft intercom system.

TCAS surveillance and computer functions were provided by a TCAS Experimental Unit (TEU). The TEU was built by Lincoln Laboratory and has been used extensively in the development of the fixed-wing TCAS design. The TEU employed waveforms, reply processing algorithms, and tracking algorithms that conformed to current TCAS II specifications in all significant particulars. The threat detection logic was specially modified for rotorcraft use (see section 1.2 below). The tracked positions of all traffic of interest were updated once per second and passed on the the AID for display to the pilot.

1.2 TCAS Logic

The TCAS logic employed was a Lincoln Laboratory version modified to emulate the the initial traffic advisory logic for rotorcraft as described in Refs. 2 and 3. No resolution advisories were generated by this logic and there was no provision for sensitivity level control.

Fig. 1.2 TCAS display installed in the Long Ranger cockpit.

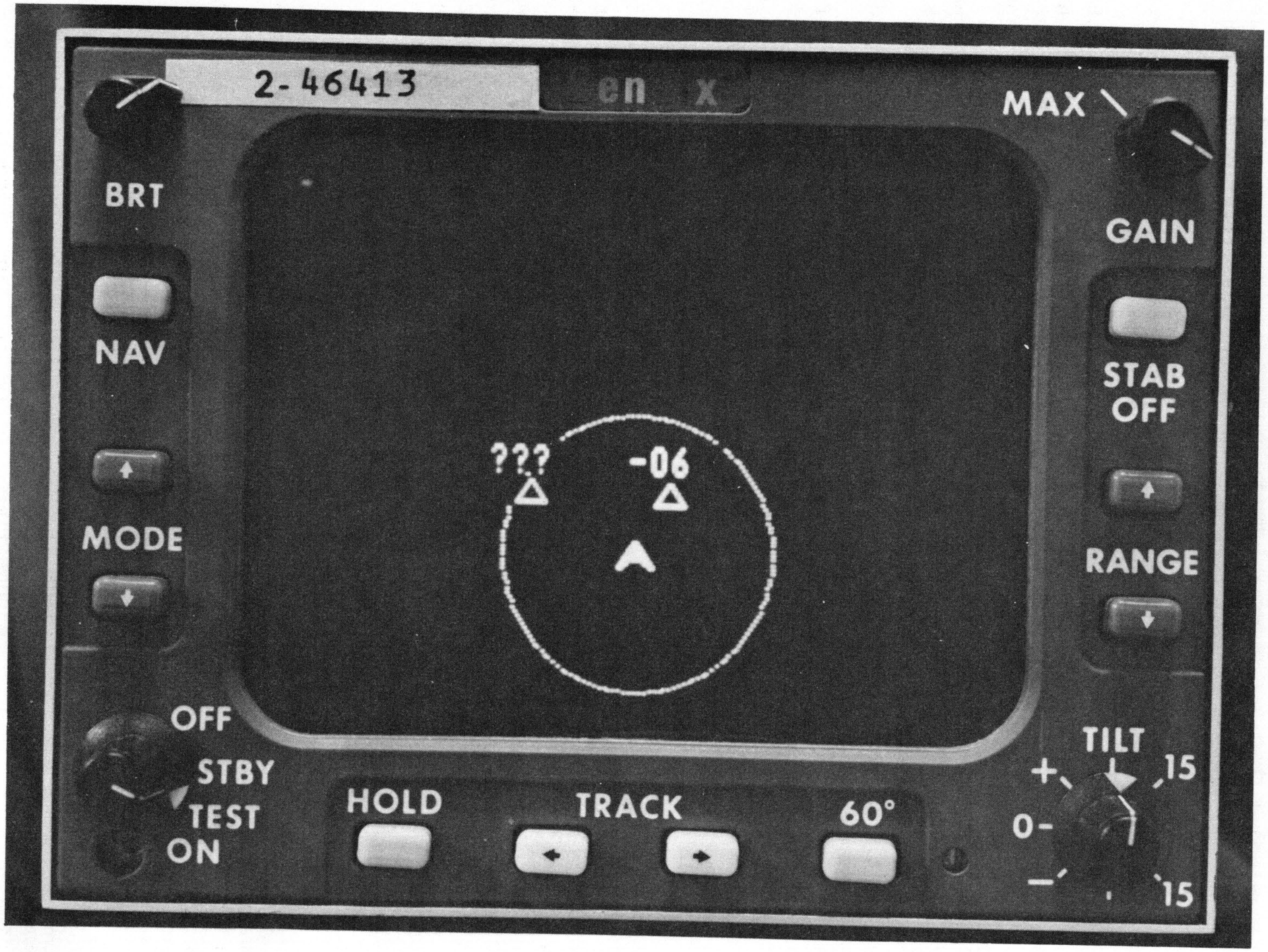

Fig. 1.3 TCAS display showing two intruder aircraft.

TCAS tracks were not displayed to the pilot unless they satisfied certain significance criteria. Three basic classes of advisories were possible in the test installation: proximity advisories, traffic advisories (TA's), and on-the-ground (OTG) advisories. Table 1.1 provides a summary of the advisory display criteria used in the tested TCAS logic. The criterion for each type of advisory is discussed below.

1.2.1 Proximity Advisory Criteria

Proximity traffic advisories were display using white symbols on the TCAS traffic advisory display. Tracks qualified for proximity advisory status if they were within 5 nmi in range and $\pm$ 1200 ft in altitude and were not classified as on-the-ground. All tracks qualifying for proximity advisory status were displayed as soon as they qualified (unlike earlier TCAS II installations in which proximity advisories were suppressed until a target in a higher urgency class appeared). This resulted in a more comprehensive display of proximity targets than might be expected in a typical TCAS installation. These expanded criteria were useful because they provided visiting pilots with more opportunities during their brief flight for comparing the accuracy of the display with the positions of sighted traffic. The criteria also simplified TCAS operation since there was no need for the pilot to operate a switch to allow the suppressed traffic advisories to be displayed for a fixed time interval.

1.2.2 Traffic Advisory (TA) Criteria

Targets satisfying traffic advisory (TA) criteria were displayed in yellow on the TCAS traffic advisory display. When a new TA target appeared, an alerting tone was sounded through the cockpit intercom. The range criterion for TA status was that the target be projected to be within 35 seconds of reaching 0.2 nmi in range (i.e., range tau 35 seconds with DMOD parameter 0.2 nmi). However, the track immediately satisfied the range test if it came within a range of 0.5 nmi. The altitude criterion was simply that the track be within 1200 ft of own altitude and not be classified as on-the-ground. The lack of a vertical tau criterion was consistent with recommendations in Refs. 2 and 3.

1.2.3 On-the-Ground (OTG) Criteria

Targets that appeared to be on the ground (OTG) were displayed as a special symbol consisting of a white "G". A track met an OTG criterion if the altitude of the track was within 300 feet of ground level. Further details concerning this logic are provided in Section 2.4.

1.3 Pilot Backgrounds

A summary of pilot experience is provided in Table 1.2. Pilots with a variety of backgrounds were selected. Some were currently employed in corporate rotorcraft operations (primarily executive transport), some were active military pilots, and one flew a television news helicopter. Two were representatives of the FAA rotorcraft office in Washington. All had received their initial rotorcraft instruction in the military.

TABLE 1.1

ADVISORY DISPLAY CRITERIA

ADVISORY TYPE	SYMBOL	RANGE CRITERIA	ALTITUDE CRITERIA
On-the-Ground (OTG)	white "G"	≤ 5 nmi	within ± 1200 ft relative altitude and <300 ft above set ground level
Proximity Advisory	white triangle	≤ 5 nmi	within ± 1200 ft relative altitude and >300 ft above set ground level
Traffic Advisory (TA)	yellow triangle	less than 35 s to 0.20 nmi range (projected at current rate) or within 0.5 nmi	within ± 1200 ft relative altitude and >300 ft above set ground level

TABLE 1.2

SUBJECT PILOT BACKGROUNDS

Pilot ID	Rotorcraft Hours (TOT)	MISSION EXPERIENCE Executive/ Corporate	Military	News Gathering	Offshore	Other
a	5200	X	X			
b	4000	X	X			
c	1200		X	X		
d	5000	X	X			
e	500		X			
f	5000		X			
g	700		X			
h	8000	X	X			
i	1300		X			
j	7800	X	X	X	X	
k	2400	X	X		X	X
l	4500		X			X

1.4 Pilot Pre-flight Briefing

Before flying, pilots received a 15 minute briefing describing the TCAS installation, the display symbology, and the proper crew procedures for use of TCAS. This briefing included color photographs of the display for representative traffic situations. Pilots were given a general description of the type of questions that would be asked after the flight.

1.5 Route

The helicopter departed from the Lincoln Laboratory Flight Facility at Hanscom Field in Bedford, Massachusetts. It flew into Boston using the northwest helicoptor route (see Fig. 1.4). After passing Logan International Airport, the helicoptor reversed course, flew back to downtown Boston, and then flew a few miles outward on the western helicoptor route. It then reversed course, returned to downtown Boston, and returned to Hanscom Field via the northwest route. The duration of each flight was approximately 30 minutes.

1.6 Data Collection

During the flight, the Lincoln Laboratory test pilot recorded the times of any interesting TCAS activity. Surveillance data and advisories were recorded on magnetic tape. After the flight, the visiting pilots were asked to complete a three page questionnaire. Then they were debriefed and additional verbal comments were added to their questionaire responses.

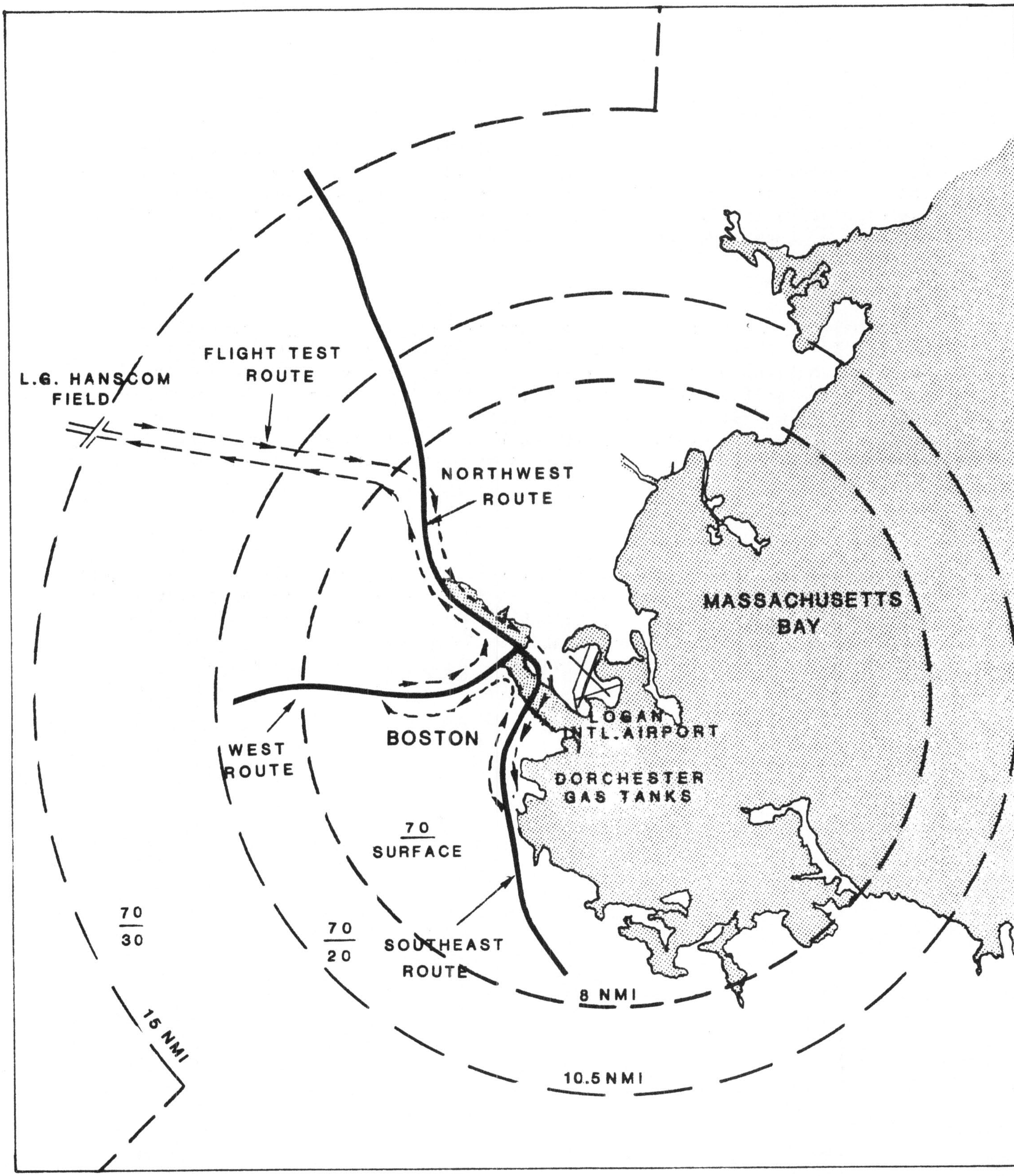

Fig. 1.4 Flight test route for rotorcraft TCAS mission. Designated rotorcraft routes and Boston TCA contours are shown.

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2.0 PILOT EVALUATION OF TCAS

In the following paragraphs, the pilots are identified by the letters a, b, c, d, e, f, g, h, i, j, k and l. The comments include those provided verbally after completing the questionnaire as well as those actually written on the form. Notes provided by the author are enclosed in square brackets.

2.1 Comparison of TCAS Advisories with ATC Advisories

The first question on the post-flight questionnaire asked pilots to compare the TCAS advisories to ATC advisories. The results are given in Fig. 2.1.

In previous experiments using a TCAS installation in a fixed-wing aircraft, pilots have indicated that the bearing of TCAS is clearly more accurate than that provided by ATC. For the helicopter installation, the subject pilot consensus is that the TCAS bearing accuracy is about the same as ATC. It also appears that helicopter pilots do not rate the reliability of the TCAS advisory as greatly different from that of ATC. Despite this, it is clear that pilots feel that helicopter TCAS advisories are more useful than those from ATC. This can be attributed to two advantages of TCAS advisories. First is the ability to constantly update the traffic location and thus prevent problems of visual search based on obsolete information. Second is the graphic nature of the traffic display that provides more effective information acquisition than voice transmissions.

A disadvantage of the TCAS advisory was that TCAS could not specify the traffic aircraft type (e.g., rotorcraft or fixed-wing). This sometimes increased the difficulty of verifying that visually acquired aircraft were the ones referred to by the traffic advisory.

2.2 Problem List

The second section of the questionnaire asked subject pilots to indicate whether or not they experienced any problems with the use of TCAS. Nine types of problems were suggested as possibilities and a provision for writing in "other problems" was provided. The replies are provided in Fig. 2.2.

Although most pilots felt that error in the displayed bearing of traffic was "no problem", three pilots (b,d, and l) rated bearing accuracy as a serious problem. Pilot d noted that the bearing "lags somewhat". He mentioned that at one point "after completing a turn and stabilized, traffic appeared to initially go left when actually it was going right". Pilot l felt that the main problem was that the bearing information was displayed with much greater resolution on the display than the accuracy of the system justified.

Six pilots noted a slight problem with "erratic or inexplicable jumps in the traffic advisory". Some of these discontinuities were due to bearing errors that existed immediately after a track started.

Compare the TCAS traffic advisories to the traffic advisories received from ATC:

WITH RESPECT TO:	TCAS MUCH WORSE	TCAS SOMEWHAT WORSE	TCAS ABOUT SAME	TCAS SOMEWHAT BETTER	TCAS MUCH BETTER
Accuracy of Bearing Data	-	1	bcdehjk	g	afi
Reliability	-	1	bcehj	ad	fgik
Workload Caused by Advisory Service	-	k	abcl	dghj	efi
Value in Aiding Visual Search	-	d	-	cjl	abefghik
Overall Contribution to Flight Safety	-	-	1	bcek	adfghij

Fig. 2.1. Comparison of TCAS traffic advisories to ATC advisories.

Indicate the extent to which you experienced the following problems:

	SERIOUS PROBLEM	SLIGHT PROBLEM	NO PROBLEM
Confusion over which traffic was causing the alarms	-	bejk	acdfghil
Unnecessary (nuisance) alarms	-	bdejk	acfghil
Erratic or inexplicable jumps in the traffic advisory	-	bdefkl	acghij
Errors in the displayed bearing of traffic	bdl	k	acefghij
Disappearance of traffic advisories earlier than desired	-	d	abcefghijkl
Lack of traffic advisory on traffic of interest	b	-	acdefghijkl
Problems reading/interpreting display	-	bkl	acdefghij
Problems hearing/understanding aural alerts	-	eh	abcdfijkl
Use of "G" symbol when target was actually in the air	-	c	abcdefghijk

Fig. 2.2. Problems noted by subject pilots.

2.3 Pilot Use of Traffic Advisories

One pilot commented that helicopters are versatile aircraft that engage in many diverse types of operations. Hence, helicopters employ a wide variety of avionics configurations and TCAS may have to be tailored to the different situations. He felt that there might have to be pilot-selectable switches to adjust the system sensitivity to different levels for different operations.

It appeared that pilots were more concerned with locating other helicopters than fixed-wing traffic. This was because fixed-wing traffic did not normally descend to the altitudes at which the helicopters were flying. Yet for reported near-misses involving helicopters, the intruder is often a fixed-wing aircraft.

Two pilots expressed concern that pilots might assume that the TCAS display showed all traffic when in fact it showed only the transponder-equipped traffic. They suggested that pilot training should emphasize the need to remain vigilant for non-transponder traffic.

One pilot commented on how he would react if TCAS were to indicate traffic overtaking him from behind. He stated that if the traffic appeared to be overtaking on the right side (the side on which he was sitting), he would make a brief turn in order to visually check separation. If the traffic appeared to be approaching on the left side, he would probably not turn since his vision was obstructed in that direction. However, he added that if he were really concerned, he might make a 360 degree turn to the right. These comments raise some interesting questions concerning how pilots should be trained to use the traffic advisory display when targets are approaching from an obstructed bearing.

2.4 On-the-Ground Tracks

2.4.1 Requirement for On-the-Ground Logic

In a standard TCAS II installation, a radar altimeter installation is used to determine the altitude of the TCAS aircraft above the ground. All intruder tracks that are within approximately 180 feet of this ground level are considered to be on-the-ground (OTG). These OTG tracks are not processed by the TCAS logic and are not displayed on the traffic advisory display. This OTG logic is intended to reduce display clutter and to reduce the frequency of unnecessary TCAS alarms.

A radar altimeter will normally be unavailable in a rotorcraft TCAS installation. This means that any OTG determination in rotorcraft must be based primarily upon barometric altitude. Two factors can reduce the reliability of such a determination. First, ground level varies with location. Second, the pressure corresponding to a given altitude above the ground varies with atmospheric conditions.

In early helicopter flights into the Boston area, no OTG suppression was employed. It was found that in the vicinity of Logan International Airport, up to five or six on-the-ground aircraft appeared on the display, producing unacceptable display clutter. Thus, some type of special OTG logic appeared to be desirable. Consequently, special logic was added to the installation that declared a track to be OTG if it was below a specified pressure altitude. The threshold altitude was selected manually to correspond to 300 feet MSL for the barometric setting at the time of the flight. In an actual installation, automatic rather than manual threshold selection may be possible (see discussion below).

2.4.2 Display of On-the-Ground Tracks

Once a track is declared to be OTG, there are two options for how it is treated by the display. One option, used by the current TCAS II, is to totally suppress its display. The other option is to display the track with a special OTG symbol. Pre-test experience raised questions concerning the wisdom of total suppression. Some rotorcraft pilots considered OTG advisories to be useful information, not nuisances. One reason for this is that unlike fixed-wing operators, helicoptors can take off from many different points in a high-density traffic area. And the time from take-off to reaching the operating altitude of the TCAS helicopter could be short. Helicopter pilots apparently make it a practice to inspect each helipad for activity as they approach it. Hence, the on-the-ground advisories assisted in locating potential intruders taking off from the various helipads that were scattered around the city. In addition, one pilot noted that in helicopter operations from remote, temporary sites, the pilot sometimes has difficulty locating the landing area being used. He felt that seeing advisories for helicopters on the ground would assist in operations in such areas. Another consideration is that the OTG determination is not as reliable as that in a TCAS II installation. If a track is falsely declared OTG and appears in a location where no airport or helipad is known to exist, then pilots are likely to initiate the needed visual search. Thus the problem of incorrect OTG determination is ameliorated. For these reasons, it was decided that OTG tracks would be displayed using a symbol consisting of the single character "G". This symbol reduced the total amount of display area required for track display by more than 75 per cent, greatly reducing the clutter problem. It is immediately distinguishable from in-the-air symbols (triangle plus altitude tag).

2.4.3. Evaluation of On-the-Ground Track Display

A special set of questions (see Fig. 2.3) provided an evaluation of the OTG logic. The questions were designed to encourage criticism of the design. It can be seen that in general the pilots approved of the "G" symbology. The principal criticism concerned the fact that rotorcraft taking off from the ground would not appear as in-the-air targets until they reached 300 feet altitude. This criticism could be largely resolved by using a refined OTG criteria that declares all tracks with non-zero vertical rate to be in-the-air.

The TCAS system flown at Lincoln Laboratory used a "G" symbol to show targets thought to be on the ground. Please indicate the extent to which you agree or disagree with the following comments concerning the "G" symbols.

	DISAGREE	NOT CLEAR	AGREE
The "G" targets caused unacceptable display clutter.	cdfgij	be	ah
The "G" targets should simply be dropped from the screen (don't show them at all).	bcdfghij	-	ae
Displaying the location of the "G" targets provides useful information.	a	bc	defghij
The criteria for using a "G" needs to be improved.	fij	d	abcegh

Fig. 2.3. Evaluation of the on-the-ground logic.

Although pilot h stated that the display of OTG tracks should be pilot-selectable, only one pilot (pilot "a") clearly rejected the OTG symbology. He stated that the "G" symbols produced too much display clutter in the vicinity of Logan International Airport and that he was not interested in them there. He also felt that the OTG aircraft at helipads would not be shown due to obstruction by buildings (although test data shows otherwise).

In evaluating pilot responses, it has been noted that display clutter problems normally appear most severe in the initial use of the system. If information is properly coded (by color or symbology), a pilot who has become familiar with a display tends to automatically filter out the information that is not of interest. Since all of the subject pilots had less than one hour of flight experience with the display, their assessment of the display clutter problem is likely to be on the pessimistic side. Thus, it appears from the favorable consensus of Fig. 2.3 that the "G" symbology did resolve the display clutter problem that was noted in pre-test flying.

2.4.4 Possible Refinements to On-the-Ground Logic

Improved OTG logic should be investigated in future TCAS installations. As mentioned earlier, it is possible to use an automatic rather than manual setting of the OTG altitude threshold. One way of doing this would be to use own Mode-C altitude at TCAS start-up as an initial estimate of ground level. This estimate could be lowered if aircraft tracks were subsequently observed at a lower altitude.

Refined logic for transitioning to in-the-air status is also possible. As mentioned earlier, the most important such criterion is one that would declare all aircraft with clearly non-zero altitude rates to be in-the-air. This would allow a quick transition in status for helicopters taking off after being declared OTG. A second criterion might declare a target to be in-the-air if its closing rate were greater than the maximum rotorcraft airspeed plus some buffer (say, 40 knots). This would ensure proper declaration of all intruders except those flying more or less parallel to own heading.

The most fundamental problem is that if terrain height varies greatly over the flight, simple ways of automating the altitude threshold selection may not be reliable. Manual input may then be required.

2.4.5 User Implementation Options

At this time no single OTG logic design appears to be suitable for all users in all locations. It is likely that each user would have to select the options that were most suitable for the particular flight environment in which the system would be used. The options selected for flight in high traffic densities with minimal terrain variation (e.g. Long Island to New York City) might be quite different from those selected for low traffic density with steeply varied terrain (western mountain regions).

2.5 Overall Rating of TCAS Utility

In order to provide an overall rating of the utility of the TCAS installation, pilots were asked the following question:

What is your rating of the utility of the TCAS in the Long Ranger: Not useful/ Marginally Useful/ Useful/ Very useful?

Six pilots (b,c,d,e,k,and l) rated the installation as "useful". Six pilots (a,f,g,h,i, and j) rated the installation as "very useful". Thus no pilot, despite individual criticisms of particular system features, felt that the usefulness of the system was questionable.

2.6 Changes and Improvements Indicated by Visiting Pilots

Subject pilots were asked to indicate areas in which the system should be improved prior to approving a TCAS design for helicopter use. Figure 2.4 shows the form of the question and the responses received.

Two pilots suggested changes in the traffic advisory detection parameters. Pilot d suggested that the display scale should be varied so that it could be "1 nmi max range for traffic areas, 3 nmi for control zones near airports, 5 nmi for en route". Pilot e suggested that G targets be dropped since they were "no factor until airborne".

Four pilots suggested changes in the aural alerts. Pilot e suggested that the tone of the aural alerts be changed since the current tone seemed to interfere too much with the air traffic controller's transmissions. Pilot h stated that the "aural alert sounds too much like radio interference. Use another tone, however don't duplicate the radar altimeter alert tone." Pilot a found the aural alerts annoying in high traffic density areas. Pilot g commented that "I didn't recognize the aural as an alert at first. I think a more distinctive audible would be helpful."

Two pilots suggested changes in the CRT traffic display. Pilot c suggested that a range scale be drawn on the display screen. Pilot l suggested that the size of the alphanumeric characters be increased to improve readability. In particular, he felt that the plus and minus sign of the altitude tag was difficult to read.

The location of the display in the far left side of the cockpit was a known artificiality of the test installation and hence was not commented upon by the subjects.

Four pilots suggested improvements in the accuracy of the bearing information. Pilot l objected primarily to the fact that the bearing indication on the display had greater resolution than the actual accuracy of the bearing data. Pilot f commented: "All advisories were extremely accurate. On occasion, the target would be erratic as it appeared on the screen." This comment probably refers to an initial period of instability

IN THIS AREA:	CHANGES MANDATORY	CHANGES DESIRABLE	CHANGES NOT NECESSARY
ranges/altitudes at which traffic advisories appear	-	de	acfghijkl
aural alerts	eh	ag	cdfijkl
CRT traffic display	-	cl	adefghijk
accuracy of bearing information	l	bfk	acdeghij
reliability of alarms	b	e	acdfghijkl
Other: Pilot-selectable display of G targets	gh	-	(not mentioned by abcdefijkl)

Fig. 2.4. Evaluation of overall utility.

immediately after a track is started. Pilot b noted that some aircraft had been shown at incorrect bearings and felt that this undermined his confidence in the display. Pilot f had no specific comments other than that increased accuracy was desirable.

Two pilots suggested improvements in the reliability of alarms. Pilot e recommended improving the reliability of advisories because he had noted "spurious targets that would appear/disappear from the screen never to return." Pilot b questioned TCAS reliability because of aircraft seen but not displayed, although he added that the aircraft in question might have been outside the 1200 ft altitude cut-off.

In the "other" category, two pilots (g and h) felt it was mandatory to make the display of on-the-ground targets pilot-selectable. The other pilots provided no comment in the "other" category.

3.0 OTHER RESULTS

3.1 Rate of Alarms

For flights that occurred during the peak rotorcraft traffic times (0730-0900 and 1530-1730), 12-15 yellow level traffic advisories were typically issued. For non-peak times, about 4-5 were typically issued. ATC verbal traffic advisories were received for about one-third of the yellow TCAS advisories. The type of aircraft causing the advisory seem to be a function of the specific traffic mix and the runway configuration in use at Logan International Airport at the time of the flight. For some missions, the yellow advisories were mostly from jet traffic flying overhead on approach or departure from Logan International. In other missions, the yellow advisories were mostly from other helicopter traffic.

There was no obvious pattern for predicting the one-third of the TCAS advisories that ATC called. Pilots rejected the hypothesis that ATC was calling only the most significant traffic. Several instances were cited in which only a TCAS advisory was received for traffic that was of genuine concern. Controller workload limitations and imperfect low-altitude surveillance may account for many of these instances.

3.2 Detection Criteria Based on Vertical Rate

It was originally suggested (Ref. 2 and 3) that since rotorcraft installations do not issue resolution advisories, vertical rate criteria are not needed in these installations. Hence vertical tracking was deleted from the logic and a simple 1200 ft immediate altitude test was employed for issuance of a TA. This logic appears to be responsible for many unnecessary TA alarms in the test flights. When flying on the rotorcraft route that passed under the departure route from Logan International Airport, many TA's were generated by fixed-wing aircraft that were above own altitude and climbing rapidly. These aircraft were clearly of no concern to the helicopter. For a helicopter that is operating at only 500 ft AGL, it appears unreasonable to issue a TA for traffic that is at 1600 ft AGL and rapidly climbing. These alarms could be eliminated by combining a reduced immediate altitude threshold (perhaps as low as 500 ft) with a vertical tau test.

Another area in which vertical rate criteria could be useful is in the on-the-ground logic (see Section 2.4). Aircraft with non-zero vertical rates can be assumed to be in the air.

3.3 Proximity Range Threshold

During debriefing, several pilots were asked the following question: "If you could select a value for the proximity range threshold, what would you select? Is the recommended value of 2 nmi acceptable?" Pilot replies were as follows:

1) "If I had a switch, I might go from 5 nmi in remote areas to 2 nmi in high density areas."

2) "If I had a choice, I would set the range threshold to 5 nmi, although I realize that I might not be able to see aircraft that far out. In a few situations (such as very high traffic densities -New York City for example), 2 nmi might be best. If only one value was possible, 2 nmi would be acceptable."

3) "Related to helicopter operations, a two mile range ring would appear to be adequate for the terminal area. A means of switching to an extended range for en route operations would be desirable."

4) "I would recommend 3 nmi instead of 2 nmi for range threshold. The reason for this is that I am often keeping track of aircraft beyond 2 nmi because I think they might be a factor in the future. Having them on the display would help me do this."

In the judgement of test personnel, the display of traffic beyond 3 nmi in range was seldom useful since such traffic was difficult to visually acquire and was seldom of concern to the pilot. A significant penalty associated with the display of such traffic was that the scale required to display traffic to 5 nmi resulted in all traffic in close proximity being displayed in a very small central portion of the screen. This decreased display readability and increased clutter problems for the nearby traffic that was usually of most interest. This would argue for use of a maximum range of no more than 3 nmi.

3.4 The Rotorcraft Operational Environment

In the Boston area, a special ATC radio frequency is reserved for rotorcraft. During busy periods, the controller often issues broadcast traffic advisories in which the absolute locations of two or three rotorcraft are transmitted without regard to the aircraft to which the traffic is of interest.

During the flights it was noted that the bearing of traffic advisories provided by ATC was subject to considerable error. Some pilots attributed this to the fact that the ground track of a helicopter is not as straight as for fixed wing aircraft. This could be one reason that that traffic advisories issued to the helicopter were frequently stated in terms of the absolute (not relative) location of the traffic, e.g., "You have a Jetranger operating near Fresh Pond, 400 feet".

Pilots were usually more concerned with locating other helicopters than with locating fixed-wing traffic. This was because fixed-wing traffic seldom appears at the altitudes at which the helicopters were flying. Many helicopter pilots that fly primarily from helipad to helipad are seldom in proximity to fixed-wing traffic at their altitude. It should be noted however, that for 80 per cent of the reported near-misses involving helicopters, the intruder is a fixed-wing aircraft (Ref. 4).

Several pilots noted that many helicopters do not have encoding altimeters and that consequently TCAS would not provide altitude for many targets of interest. Apparently, the lack of encoders in helicopters is not so much a matter of the cost of the equipment as it is a desire by operators to reduce weight and complexity of the avionics installation.

3.5 Display and Aural Alert System

Certain changes to the display and aural alert system are suggested by the flight test results. However it is often difficult to make a firm recommendation for a change without actually testing the change. The following findings are tentative to this extent.

1) The tested installation provided a dedicated TCAS display that allowed continuous (unsuppressed) display of proximate traffic advisories. This differs from earlier fixed-wing TCAS installations in which proximity targets are not displayed unless there is at least one target satisfying the TA criteria or unless a "tracks" switch has been pressed by the crew. The continuous display mode was successful and should be considered for future rotorcraft installations. The arguments for this mode are as follows: First, for a traffic advisory-only system operated in VMC at rotorcraft altitudes, the additional awareness of traffic that proximity advisories provide is of value to the pilot. Second, the need for a manual switch to allow the pilot to view the supressed traffic advisories (with its attendant workload) is eliminated.

2) Consideration should be given to reducing the altitude tag for altitude-unknown aircraft to a single question mark (rather than three). This will decrease the size of the altitude-unknown symbol and thus reduce display clutter in high density areas.

3) Larger + and - symbols should be employed on the display. Currently these symbols are smaller in size than other alphanumeric characters. Consequently, some pilots were observed to misread the sign of the altitude tag.

4) In order to more efficiently use display area, a design should be considered in which zero range is mapped into a circular locus around own aircraft symbol. This would provide more area for the display of proximate traffic while retaining an accurate bearing presentation. It would also alleviate the problem of determining target bearing when own aircraft symbol is being overwritten.

5) A more distinctive aural alert sound of shorter duration would appear to be desirable. Some pilots felt that the current aural alert sounded like radio interference and that it interferred too much with ATC radio transmissions.

4.0 PRINCIPAL CONCLUSIONS

The principal conclusions that follow are based on the general consensus of subject pilot responses:

1) The installation provided a valuable enhancement to the pilot's normal visual acquisition capabilities. In fact, pilots felt that it provided a more valuable service than that associated with current ATC traffic advisories.

2) Pilots did not feel that TCAS bearing errors brought the value of the installation into question. The bearing errors associated with the rotorcraft installation were roughly comparable to those of ATC traffic advisories. However, in some cases bearing errors were large enough to make correlation of TA's and visual sightings difficult. Improvements in bearing accuracy performance should continue to be a goal of the rotorcraft program.

3) The rate of traffic advisories (yellow level advisories) for these flights was 5-10 per hour, about 25 times greater than for TCAS units carried on jet transport aircraft. Pilots seemed to view the alarms as useful and generally justified by the proximity of the traffic.

4) Because of the lack of radar altimetry in rotorcraft, difficulties arise in determining the on-the-ground status of tracks. These difficulties can be addressed by special logic for on-the-ground tracks. However the best design options in this area have not yet been established.

5) Many of the alarms that pilots considered unnecessary were due to aircraft with high vertical rates that had already crossed the cruise altitude of the TCAS aircraft. Detection criteria based on vertical tracking would be useful in lowering the rate of these alarms. An immediate altitude threshold of approximately 500 feet in conjunction with a vertical tau criterion appears desirable. Vertical tracking might also be of value in the on-the-ground logic.

6) Among display options that should be allowed are the continuous display of proximate targets and extension of the proximity range threshold from 2 nmi to 3 nmi.

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