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Helicopter User Survey: Traffic Alert Collision Avoidance System (TCAS)

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April 1985

Final Report

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16. Abstract

This document describes the data collection methodology, and the results obtained from the Traffic Alert and Collision Avoidance System (TCAS) User Survey. The survey was conducted during the fall, spring and early summer of 1984. The survey examined helicopter operator and pilot responses in three particular areas of interest: 1) The nature of helicopter near mid-air collision encounters, 2) Pilot Display Preferences, and 3) User price thresholds for a helicopter TCAS.

The survey revealed that only a small percentage of near mid-air collisions involving helicopters are reported, although pilots assert that mid-air collisions pose a significant hazard to flight safety. This report contains breakdowns, by operator group, of significant characteristics of helicopter operations and their associated NMAC hazards which should be addressed in the design of a helicopter specific TCAS.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

During the past year, the FAA has completed preliminary testing and evaluation of a Traffic Alert and Collision Avoidance System (TCAS), designed to provide traffic separation assurance for air carrier aircraft. The system tested, the minimum TCAS II, provided both traffic advisory (relative position of intruding traffic) and conflict resolution (vertical plane only) data from which the pilot's could initiate their avoidance and separation manuevers. It was recognized at the time that, due to the significant differences between the operating profiles and air traffic environments experienced in rotorcraft, fixed-wing and air carrier operations, TCAS capabilities tailored to fit the needs of the air carrier might be substantially different from those which would be suitable for helicopter operations.

1.2 PURPOSE

The purpose of this survey was to investigate those aspects of helicopter operations and the helicopter Near Mid-Air Collision (NMAC) experiences which might impact on TCAS hardware and software requirements so that a TCAS or series of TCAS' could be tailored for helicopter use. The aspects of helicopter operations which were identified as being critical to the survey were:

- Frequency of NMACs as a function of:
  - geography
  - operator group
- NMAC Experience as a function of:
  - Encounter Airspeed
  - Encounter Altitude
  - Closest Approach Distance
  - Prevailing Weather Conditions
  - Preferred Avoidance/Escape Maneuvers
  - Types of Aircraft involved
  - Flight modes at the time of the encounter
- Pilot Rankings of Significant Cause/Factors
- MODE-C Transponder Equipage
- Mission Profiles which would inhibit TCAS utility

In addition to providing data which would assist in the software design for the helicopter TCAS, the survey was intended to poll pilots regarding their preferences for particular TCAS capabilities, ancillary data requirements and display formats, as well as their price thresholds and the extent to which pilots are willing to purchase the equipment. From these data, several "strawman" TCAS designs were derived, and the size of the potential market is extrapolated for the civil helicopter population.

1.3 HIGHLIGHTS OF SIGNIFICANT RESULTS AND CONCLUSIONS

The results and conclusions obtained from the analysis of the questionnaires and on site interviews are incorporated throughout the body of this report, with a complete summary of the conclusions included in section 4.0. A summary of the significant conclusions derived from the analysis of the questionnaire are presented below:

<u>Survey Sample and Census Data</u>

- The survey sample approximates the distribution of civil helicopter pilots and operator types nationwide
- The geographical locales surveyed represent those areas exhibiting the highest frequency of reported NMAC encounters.
- Based upon an extrapolation of census results to the civil helicopter community at large, Transponder equipage is projected as follows:
    - 4096 CODE Transponder: 91%
    - Transponder w/Encoding altimeter (MODE C): 48%.

<u>Surveyed Pilots NMAC Experiences</u>

- Helicopter NMAC's involving both fixed-wing and other rotary wing aircraft are far more frequent, and present a significantly greater hazard than can be supported by voluntarily reported NASA data.
- Rotary wing-rotary wing encounters may represent up to 23% of all helicopters NMAC.
- The mean NMAC encounter altitude for helicopter NMAC's is low, approximately 750 ft AGL, a reflection of the low altitude at which they operate, and of their most critical phase of flight, i.e., approach and departure phases.

- Nearly 21% of helicopter NMAC's occurred in reduced ceiling and visibility conditions.

- The NMAC environment of rotorcraft does not differ significantly from that of light general aviation aircraft (i.e., location - near airports; airspeeds - less than 140 knots; altitude - less than 1000 feet; and flight mode - straight and level). As such, a TCAS developed for helicopters may be applicable to fixed-wing as well, or vice versa.

- Proximity to the ground and reduced ceilings will significantly reduce the utility of vertical only conflict resolutions, in either climb or descent.

- At low altitude, pilot preference for horizontal conflict avoidance manuevers is sharply evident. That preference decreases, with more emphasis placed on a combination vertical and horizontal manuever as altitude increases. Above 1500 ft AGL, selection of a vertical, horizontal or combination resolution should have little impact upon a pilot's tendency to execute the manuever.

- The helicopter's low airspeed allows a substantially smaller volume of protection than that necessary for air-carriers. The maximum horizontal protection radius for a high-speed (132 knot cruise airspeed) helicopter, is approximately 4.8 NM.

- Low speed also infers that many conflicts will result from being overtaken by higher speed fixed-wing aircraft, approaching from the critical quadrant (left/rear). In this event, a horizontal protection radius optimized for a worst case, head-on collision would provide twice the alert time for intruders approaching from the critical quadrant.

<u>TCAS Capability, Display, and Price Thresholds</u>

- Extrapolated across the entire civil helicopter community, survey results show, that by a wide margin, pilots do not desire exotic TCAS capabilities. For the 5 rated capabilities, the percentage of those preferring each capability are shown:

- Proximity Warning (PW) (TCAS "A") 11.5%
- Proximity Warning and Critical Quadrant Indication (CQI) (TCAS "B") 43.1%
- Proximity Warning, CQI, Relative Altitude (TCAS "C") 36.1%
- PW, CQI, Relative Altitude and Conflict Resolution Advisory (TCAS "D") 3.1%
- Above capability coupled with flight controls (TCAS "E") 6.2%

- Pilot rating of effectiveness of various display formats also indicates a preference for simplicity of the display. The following is a rank ordering of the display references:

  - Combination - (with Audio Tone and warning lights as the first choice for those ranking "combination" as best)
  - Audio Tones
  - Warning Lights
  - Video Display
  - Synthetic Voice Warning
  - Digital Display

  The most frequently preferred "combination" display formats were:

  - Audio Tones and Warning Lights (6)
  - Audio Tones and Digital Displays (3)
  - Audio Tones, Warning Lights, Synthetic Voice Warnings (2)
  - Warning Lights, Video Display and Synthetic Voice Warnings (2)
  - Warning Lights, Digital Display (2)
  - Synthetic Voice and Digital Display (2)

- TCAS Price Thresholds, as cited by the survey pilots, do not vary significantly with respect to increasing TCAS capabilities. Price threshold levels at which half the pilot's desiring a particular capability might be expected to purchase it are as follows:

- TCAS "A" - $3,525
- TCAS "B" - $4,700*
- TCAS "C" - $3,525
- TCAS "D" - $7,900
- TCAS "E" - $5,000

- Pilot's tendency to purchase a TCAS was neutral, with a slight bias towards purchasing the equipment.

- Less than 5% of the pilots surveyed indicate that they would purchase the TCAS immediately. Over 13% declared that they would not purchase.

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*The $4,700 price threshold is impacted by a single pilot (air carrier) who indicated a willingness to pay over $10,000 for the TCAS "B" capability.

2.0 SURVEY DESCRIPTION AND METHODOLOGY

The helicopter TCAS User Survey was comprised of four separate but interrelated efforts, which were performed chronologically. Those four efforts were:

- Questionnaire Development
- Data Acquisition and Analysis Plan
- Data Collection
- Data Analysis

The questionnaire development and survey description and methodology are described in detail in the "Traffic Alert and Collision Avoidance System (TCAS) Data Collection and Analysis Plan"[1], presented to the the FAA in October 1983. In the interest of brevity, only a brief summary of the survey and our data collection methodology are presented in this document. A detailed analysis of the questionnaire data are provided in Sections 3.1 and 3.4.

The survey consisted of 50 interrelated questions, with each group of questions designed to elicit particular information which might impact the operational requirements for a helicopter TCAS. These question groupings are briefly described in Table 2.1. The questionnaire was developed through an iterative process involving the SCT survey team and Mr. Bud Hyland, FAA APM-330, aimed at preparing a concise questionnaire which adequately covered the major areas of TCAS technical concerns. The questionnaire which resulted from this process is presented in Appendix A of this report, and it is from this questionnaire that the majority of operator and pilot responses were obtained. In March 1984, a replacement questionnaire developed by the FAA, which focused more specifically on the TCAS software requirements, was submitted to the SCT survey team, and was also presented to targeted survey groups throughout the remainder of the data collection effort.

The survey group targets were selected based primarily upon their geographic distribution throughout the country, particularly where those distributions were correlated with regions displaying an inordinate number of reported Near Mid-Air Collisions (NMAC's). In addition to geographic distributions and propensity for NMAC activity, the survey also attempted to reach operators engaged in a wide cross section of helicopter operations. Table 2.2 lists the various helicopter operator groups and professional societies who were polled throughout the survey, the number of members polled and, the number of responses received from each group. A brief look at the table seems to indicate that the California operators are over-represented in the survey, accounting for 39% of all responses. A closer examination of operator distributions and

Table 2.1 Description of Questionnaire Groupings

Questionnaire Grouping	Type of Data Derived	Purpose
Census Data	User Type Avionics Equipage Geographic Location Aircraft Type Primary Helicopter Mission	● Assure representative sample of geographic locations and user types ● Determine avionics purchase history of sample ● Extrapolation of questionnaire data to U.S. civil helicopter community

Rotorcraft Environment	● Descriptions of "most recent NMAC encounters in terms of:
	  ● Flight mode
	  ● Airspeed
	  ● Altitudes
	  ● WX conditions
	  ● Approach distance
	  ● ATC involvement
	● Avionics Performance (i.e., dead zones)
	● Preferred Avoidance Manuevers
		● Establish a "profile" of the typical NMAC encounter
		● Determine attributes of typical encounter which would promote or inhibit TCAS effectiveness

Table 2.1 Description of Questionnaire Groupings (cont.d)

Questionnaire Grouping	Type of Data Derived	Purpose
Pilots Perception of NMAC Risk	• Most critical collision quadrant • Ranking of significant collision causes/factors • Use of ATC radar advisory services	• Determine extent of NMAC threat by user group/ geographic region, mission • Determine missions which will inhibit TCAS effect-iveness
	• Frequency of NMAC encounters • Radius of anti-collision protection • High risk mission descriptions	• Broadly estimate impact of NMAC experience on potential TCAS utilization
TCAS Capability/Price Tradeoffs	• Pilots' capability preferences • Pilots' conflict information preferences • Pilots' display preferences • Price thresholds • Willingness to purchase	• Determine range of capa-bilities desired • Estimate potential market size for differing TCAS configurations

Table 2.2 Sources of Questionnaire Responses

OPERATOR GROUPS SURVEYED	MEMBERS POLLED	QUESTIONNAIRES RECEIVED
Florida Helicopter Pilot's Association	23	7
Appalachian Helicopter Pilot's Association	31	7
Helicopter Operators of Texas	41	4
Helicopter Safety Advisory Council	45	13
California Professional Helicopter Pilot's Association	128	32
Michigan Helicopter Pilot's Association	48	6
Eastern Region Helicopter Council	65	9
Miscellaneous	--	4

Near Mid-Air Collision experience shows however, that while a certain bias may exist in the data, it is not as significant as the 39% figure would seem to indicate.

It is difficult to determine the actual number of operations and flying hours accumulated by helicopters operating in a particular geographic region of the country, as many helicopter operations are uncounted since they do not operate from FAA manned airport facilities. However, since operations are loosely a function of both the number of helicopters and number of helicopter pilots available to fly them, an estimate of probable operations can be made. The five most active states, in terms of percent of all helicopter pilots are[6]:

California	14%	Alabama	5%
Texas	10%	Washington	3%
Florida	7%		

As may be seen, California represents the largest percentage of helicopter pilots, with 40% more than Texas; 100% more than Florida; and nearly 5 times the number of helicopter pilots located in Washington State. It should be noted that two of the states in the top 5, Florida and Alabama are endowed with the two largest helicopter pilot training sites in the United States (Ft. Rucker, Alabama and Pensacola NAS, Florida).

In addition, California also leads the nation in numbers of active civil helicopters with 13% of the national total. The top five in terms of number of active civil helicopters are:

California	13%
Texas	10%
Florida	6%
Louisiana	6%
Oregon	5%

Finally, since this survey concerns pilot/operator perceptions of the NMAC hazard, it is important to determine the extent of that hazard as reported by pilots. During the period from March 1978 to December 1982 a total of 187 NMAC were reported to NASA through the Aviation Safety reporting system. Of those 187, over 65 were reported in the geographic region represented by the California Professional Helicopter Pilots Association, the Los Angeles Basin. These 65 incidents represent at least 35% of all helicopter NMAC's reported in the U.S. through that reporting period.

It is not the intent of this survey to precisely reflect the general U.S. helicopter population concerning TCAS capabilities. It is important however, that the nature of NMAC encounters be explored in order to determine requirements for TCAS operations. To that end, those areas of the country where NMAC's are most prevalent should be surveyed in greater depth than those where conditions do not lend themselves to the air traffic environment where NMAC are likely to occur. Thus, the bias towards the California experience (which is most likely to manifest itself in quantities of TCAS equipment required to fill the need) is compensated by the NMAC experience data that those pilots provide.

The method employed in the data collection effort consisted of a modified Delphi technique. The Delphi Technique is an iterative survey technique aimed at obtaining a consensus of the survey group. A questionnaire is administered to the survey group which is then analyzed to determine areas of both agreement and disagreement within the survey group. The survey group is then interviewed as a group to authenticate the areas of agreement and to discuss areas of disagreement. The questionnaire is re-administered and the process is repeated until a consensus can be achieved from the survey group. In the case of the TCAS survey, the luxury of the multiple questionnaire and interview process was not available. Thus the survey group was first administered the questionnaire and then interviewed as a group, a modified Delphi process.

Because the Delphi approach provides both objective (questionnaire) and subjective (group discussion) data, the survey analysis presented may offer conclusions not readily supported by an analysis of questionnaire data alone. In these instances, data obtained in the discussion has been introduced which tends to validate the objective data, or significantly affect its derivative meaning. These instances will be discussed as they appear in the analysis.

Prior to inclusion in the data base, each questionnaire was subjected to a test to ascertain the continuity of a series of single questions in the survey. These questions were preselected and incorporated in the questionnaire specifically for the purpose of response validation. The series of questions provided a logical sequence of queries, the answers obtained demonstrated the extent to which the person surveyed understood the question being asked.

Figure 2.1 illustrates generically the methodology employed in qualifying individual questionnaires. The specific questions used in the qualification process were questions #1, 41, 15, 35 and 36.

The questions were selected based upon the assumption that TCAS desirability and pricing thresholds can be predicted based upon individual pilots' NMAC experiences and their perception of the collision hazard. This perception is tempered somewhat by the pilots' past history of avionics purchases, which reflect the economic benefit expected (thru increased mission capabilities or effectiveness) by the pilot for the particular purchase. An initial prediction might therefore be that operator groups with a low level of NMAC experiences, and using

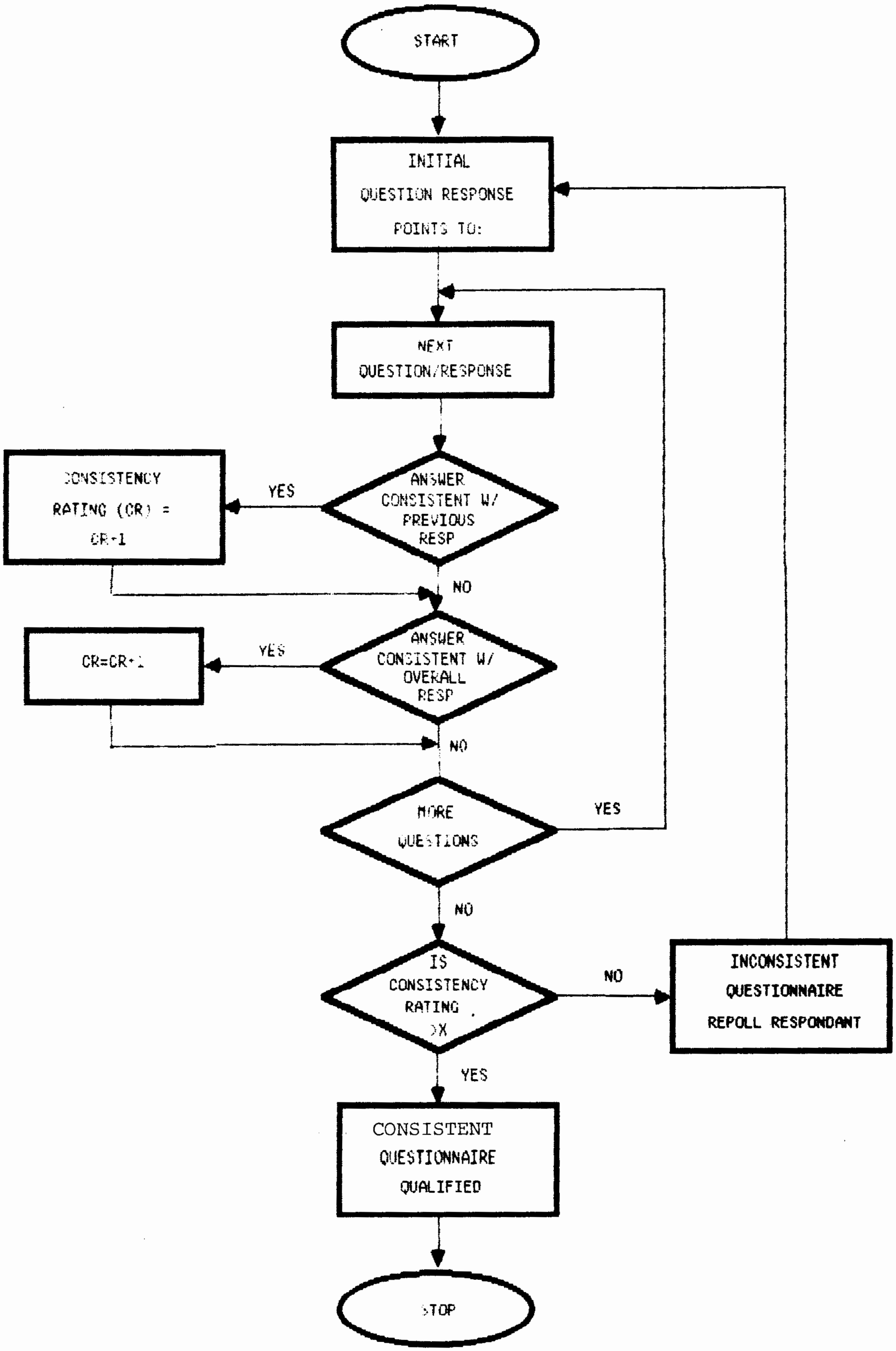


Figure 2.1 Questionnaire Validation Methodology

inexpensive equipment would require a high degree of TCAS capability at a small cost, before considering the purchase of such equipment. Conversely, a corporate pilot flying in a high density traffic area, with a number of recent NMAC's would be willing to pay more money for less TCAS capability.

Figure 2.2 illustrates the range of consistency derived from the evaluation of individual responses to the questionnaire. A questionnaire was determined to be consistent if it achieved a consistence rating greater than or equal to .5. Only two questionnaires were determined to be non-consistent, and were not included in the data base. As can be seen, the responses largely fit the pattern described above, indicating that the questionnaire was well understood by the survey partcipants. Furthermore, the consistency demonstrated by the respondents in answering the questions gives a high degree of confidence in the validity of the individual and aggregated responses.

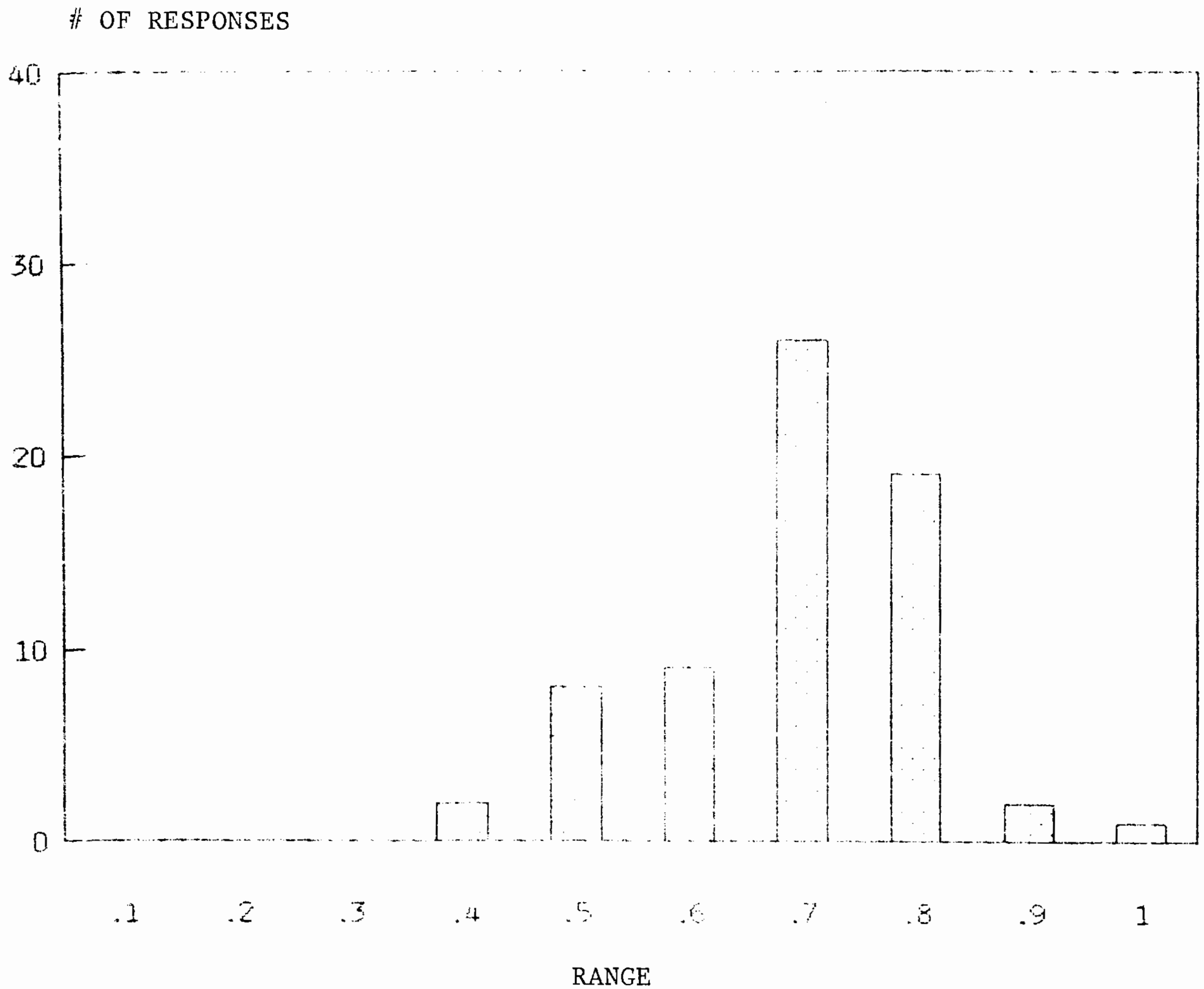


Figure 2.2 Consistency of Questionnaire Responses

3.0 DATA ANALYSIS AND SURVEY FINDINGS

3.1 GENERAL

The questionnaires returned by the individual pilots and the interchange of ideas afforded by the on-site interviews with pilot groups provides a wealth of information from which the survey conclusions were drawn. To ensure that the diverse data obtained could be analyzed in a logical and orderly fashion, it was necessary that the questionnaire be sub-divided into smaller question groupings, which were focused on a single, broad aspect of requirements for a helicopter TCAS. The question groupings selected for this task were:

- Survey Census
- Rotorcraft Environment
- Pilots' Perceived NMAC Risk
- TCAS Capability/Price Tradeoffs

The analysis and results derived from the groupings are presented in the remainder of this section. The survey census is addressed in Section 3.2. Section 3.3. combines analysis of both the Rotorcraft Environment and Pilot's Perceived NMAC risk, since the two elements are interrelated. Finally, Section 3.4. discusses TCAS Capability and Pilot Price Tradeoffs, as well as estimates/extrapolations of the potential market size for various TCAS configurations.

3.2 SURVEY CENSUS

In addition to obtaining pilot preference/perspective data on TCAS characteristics, it was necessary to obtain a description of the surveyed pilots' particular mission and equipage . This description, or census, was used as a basis for extrapolation of the survey results to the U.S. civil helicopter community as a whole, as described in the Phase I Helicopter Operational Survey, and from which were derived rough order of magnitude estimates of potential TCAS utilization for particular TCAS hardware and software configurations. In the following sections, specific elements of the census of the questionnaire respondents which have a direct bearing on the ensuing analysis are discussed.

3.2.1 Census - General Information

From over 1,000 questionnaires distributed to operators and pilots who were contacted through either mailings or our attendance at their scheduled organizational meetings, 75 completed questionnaires were received by the survey group and incorporated in this analysis. While this does represent a rather small numerical sample size, in actuality, it represents nearly .25% of the total U.S. helicopter pilot population.[3]

3.2.2 Distribution of Respondents by Primary Mission

The survey intent of sampling a wide cross section of helicopter pilots and operators with varying mission descriptions was largely fulfilled. Table 3.1 lists the various mission categories cited by respondents as their primary activity, as well as the percentage of respondents performing each mission. The table shows that the sample is involved in a full range of helicopter activities. It is interesting to note that our survey sample, which was focused mainly upon geographic distribution is roughly in agreement with the percentage distribution of helicopters in use by commercial, corporate/executive and public service operators as cited in the Phase I survey. That survey showed that of approximately 8500 civil helicopters in use, 65% were employed in commercial service, 19% by Corporate/Executive operators, and the remaining 16.0% by Public Service Operators. This is compared to the TCAS survey sample comprised of 51% commercial operators, 26% corporate and the remaining 23% public service operators, as shown in Figure 3.1.

Table 3.1 List of Primary Missions of TCAS Survey Respondents

MISSION	% of Total
Personnel Transport - Offshore	20.0%
Law Enforcement	18.3%
Corp/Executive Transport	18.3%
Medevac	5.6%
Air Charter	5.6%
Training/Instruction	5.6%
Electronic News Gathering	4.2%
Demonstration/Sales	4.2%
Utility	2.8%
Photographic	2.8%
Air Taxi	2.8%
Commuter Airline	2.8%
Drug Enforcement	1.4%
Powerline Patrol	1.4%
Experimental Flight Test	1.4%
Bank Support	1.4%
Sightseeing	1.4%

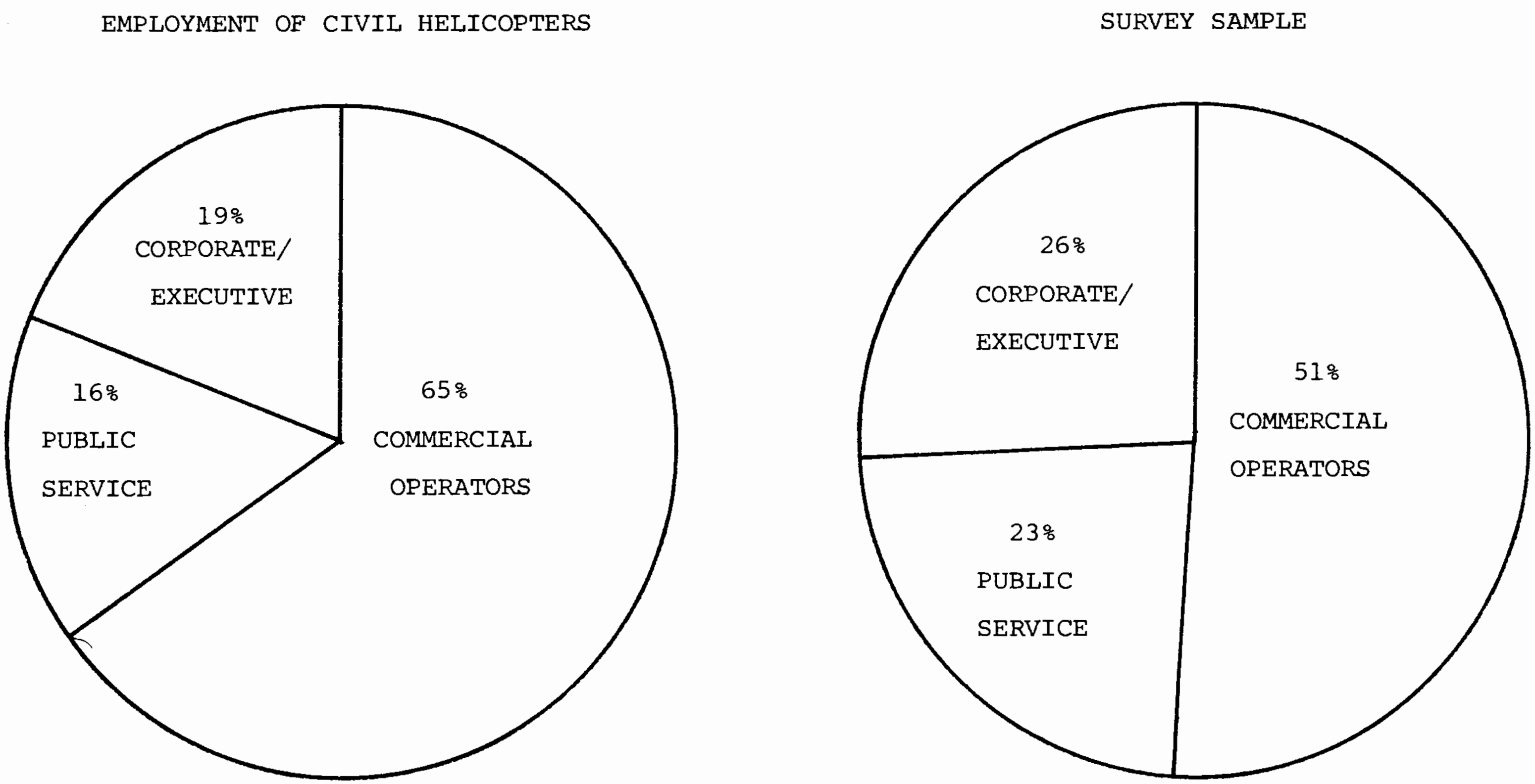


Figure 3.1 Comparison of TCAS Survey Group to Helicopter Population

3.2.3 Geographic Distribution of Survey Respondents

In addition to approximating the distribution of operator types throughout the United States, our sample also targets those geographic regions which exhibit a high number of reported near mid-air collisions. Figure 3.2 shows those areas within the continental United States where near mid-air collisions have been reported[2]. Each dot represents a reported NMAC. Note that there are significant concentrations of NMAC's centering on the Los Angeles basin, South Florida and the Atlantic Seaboard from Philadelphia up to New England. These concentrations are due largely to the density of helicopter traffic in those regions, and are therefore not unexpected. What is striking, however, is the relative absence of reported NMAC's along the Gulf Coast region, where a large number of annual helicopter operations occur. This anomaly shall be explained further in this report. Figure 3.3 shows the same NMAC history map, onto which has been overlayed the regional boundaries of the operator groups polled in this survey. It shows that the geographical areas of interest for TCAS investigation (those with a high number, and those with a low number of NMACs) are well represented in the survey census.

3.2.4 Avionics Equipage

In order to calibrate the enthusiasm which users might exhibit towards a helicopter TCAS, part of the census required that respondents list the avionics equipage of the helicopter they most frequently flew. Costs for the various types of avionics were derived by averaging the 1984 list price (no installation charges) for all manufacturers for each generic type of avionics (i.e., VOR receiver, transponders, VHF Com, etc.). These average costs were then assigned to the equipment cited by the respondents in the questionnaire, and an estimated total avionics cost per each operator group was obtained.

While average avionics costs provide interesting data, it is not particularly useful unless those expenditures can be equated to some level of mission capability. Table 3.2 lists four basic mission capabilities which are represented by the survey group, the recommended minimum equipment to perform those missions and the estimated cost for the avionics which would provide the capability.

Figure 3.2 Geographic Distribution of Helicopter Near Mid-Air Collisions in the U.S.

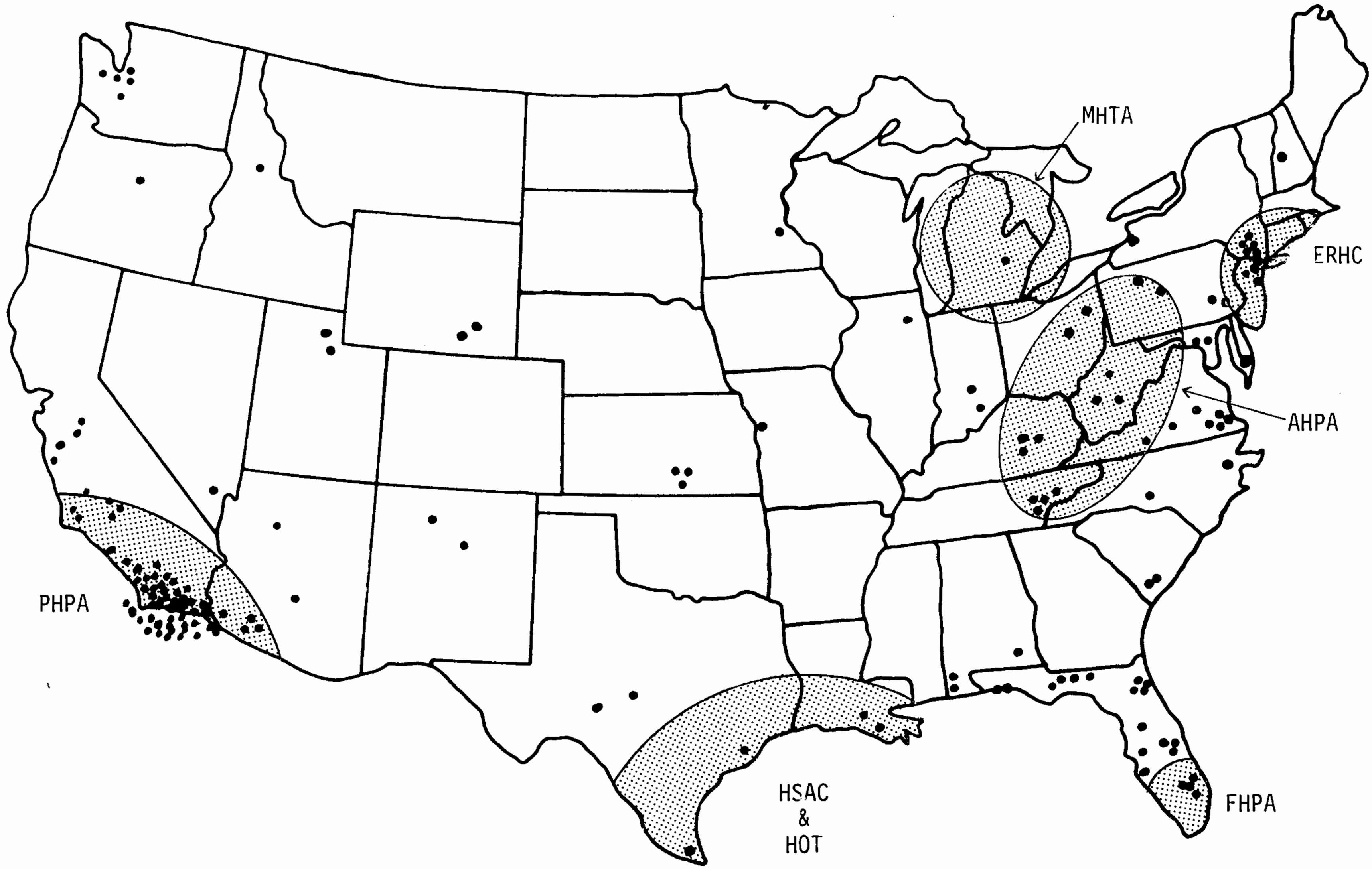


Figure 3.3 Geographic Operational Areas of Surveyed Helicopter Operator Groups

Table 3.2 Minimum Mission Avionics Requirements

Mission Capability	Minimum Recommended Equipment	Estimated Equipment Cost	Total Minimum Equipment Cost
Day VFR	VHF Communications	$ 2,640	
	Radio		$5,256
	Transponder	$ 2,616	
Night VFR	VHF Com VOR	$ 2,640	
	VOR Receiver	$ 2,102	
	Transponder	$ 2,616	$11,095
	Radio Magnetic		
	Indicator	$ 3,727	
IFR (Single Pilot)	2 VHF Com	$ 4,204	
	Transponder w/Mode C	$ 5,280	
	RMI	$ 3,737	$19,052
	ADF	$ 3,215	
	VOR/LOC	$ 2,616	
Offshore	All IFR +	$19,052	
	LORAN-C	$ 8,075	$31,092
	DME	$ 3,965	

Having approximated both the individual respondent's avionics costs and the minimum equipment costs for various mission profiles, it remains to aggregate the individual responses by operator group, and compare the average group avionics costs to the costs for the mission capabilities. Table 3.3 lists the average avionics costs for corporate/executive, commercial and public service operators. The table illustrates public service operators, principally represented by law enforcement, perform their missions with the absolute minimum equipment necessary, that mission being day and night aerial patrol (VFR). Commercial operators (other than offshore) show a small increase over the minimum necessary for night VFR operations, yet not enough to perform IFR operations as a group. This is due primarily to the lack of mission homogeneity within

Table 3.3 Avionics Expenditures By Operator Group

	Minimum	Mean	Maximum	VFR (Day) $5256	VFR (Night) $11,095	IFR $19,052	Offshore $31,092
Public Service	$2,640	$11,094	$20,158	X	X		
Commercial	$5,256	$16,979	$34,584	X	X		
Corporate	$10,573	$38,760	$145,212	X	X	X	X
Offshore	$10,790	$34,466	$56,973	X	X	X	X

that group, which represents such vastly diverse missions as sightseeing and air taxi operations. It is significant that only 25% of the respondents in this group exceeded the IFR cost threshold, while 18% of the commercial operators are not equipped to perform even night VFR operations.

Those operators who are primarily involved with offshore flying are substantially better equipped, with a mean equipment value of nearly $35,000. In fact, only one of the respondents avionics was valued less than the $31,000 minimum for offshore operations. Corporate/Executive operators appear to be the most extravagant purchasers of avionics, when compared with the minimum avionics requirements to adequately complete their mission (principally day/night VFR/IFR operations). Avionics outlays for this group exceeds by more than 80% the minimum expenditure necessary to purchase the IFR capability, indicating that there does not exist the same cost/benefit tradeoff considerations for the corporate/executive operators as is evidenced by the public service and commercial operators. In fact, through discussions with corporate operators from the Eastern Region Helicopter Association, it was determined that despite the fact that many of their helicopters are equipped and certified for IFR Flight, it was the corporate policy of many of the helicopter operators <u>not</u> to fly in instrument meteorological conditions with corporate executives on board. The primary consideration in this regard was the exposure of the passengers to undue risks. It can be argued, therefore, that for these operators, the IFR capability which they have purchased represents nothing more than a safety valve, allowing the pilots to continue a flight which began in VMC and which degraded to

IMC. These operators have opted to pay a premium for improved safety, with little or no increase in mission capability.

The economic element of the census plays an important role in subsequent analysis of TCAS requirements, and particularly in determining the potential market size for such a system. From a preliminary analysis of the avionics equipage data, correlated by operator type, several conclusions may be drawn:

- Most operators limit avionics purchases to those items which provide the capability to perform a primary or secondary mission. (Public Service, Commercial)

- In the absence of an improved capability, improved safety of operations can justify the purchase of additional avionics. (Offshore, Corporate/Executive)

The impact of these conclusions on TCAS operational requirements and marketability are readily apparent. First, in order to serve the low to mid end of the helicopter market, it should, by virtue of its design, provide some increased mission capability, at least to the extent that the improved capability will offset the costs of the TCAS. For the upper range of the market (offshore, corporate/executive) the TCAS could be justified if it provided a measurable improvement in the level of safety of their operations. Since the questionnaire respondents were told to assume some improvements in their capability to avoid near mid-air collisions, the question of safety improvement for a particular operator is largely dependent on that operators perceived NMAC hazard. These questions (safety improvement and improved mission capability) will be addressed in subsequent analyses.

3.3 ROTORCRAFT ENVIRONMENT AND PERCEIVED MID-AIR COLLISION HAZARD

3.3.1 Frequency of NMAC Encounters

One measure of the extent to which helicopter pilots perceive a hazard from near mid-air collisions is the extent to which they avail themselves of radar advisory services which might alleviate the NMACs. A series of questions were presented to ascertain the frequency of advisory requests, the number of advisories received per hour when advisories were requested and the percentage of advisories received which were of genuine interest to the pilot with respect to NMAC avoidance.

With regard to the first question, percentage of time that advisories were requested, there was a surprising unanimity of responses in each of the four operator categories for the number requesting advisories more than 50% of the time. The compiled results for each group are:

- Corporate/Executive - 64.7%
- Offshore - 64.2%
- Commercial - 61.9%
- Public Service - 57.1%
- All - 62.1%

These findings indicate a clear awareness of the NMAC hazard on the part of pilots, but does not suggest that there is an overwhelming perception of a high hazard level due to NMAC. While overall responses shown above are extremely consistent, they are the result of analysis using the lowest granularity of the responses, i.e., greater or less than 50% utilization of available advisory service. However when looking at the distribution of responses for those who requested advisories more than 50% of the time, a different picture emerges. In these cases, the offshore pilot tended to request advisories far more often than their counterparts in other groups. The results for the four groups:

	Advisory Request Rate		
	50-60%	60-90%	90-100%
Offshore	-----	55.5%	44.4%
Commercial	15.4%	46.2%	38.5%
Public Service	-----	75%	25%
Corporate Executive	9.1%	72.7%	18.2%
ALL	9.8%	58.5%	31.7%

What is striking in these data is that the offshore pilots and operators show the greatest sensitivity to the NMAC risk, despite the fact that reported NMAC in the region in which they operate (Texas, Louisiana Gulf Coast), are notable by their absence. An unsubstantiated conclusion can be drawn from this. That is, that NMAC frequency in that region is under reported. In discussions with offshore pilots in the region, it was noted that with regard to the general operational hazards in the area, collision risk was cited as the single most pressing problem. The fact that an extremely structured route system between offshore platforms and the home bases, as well as the fact that strictly enforced navigation and in-house position reporting procedures, have been voluntarily adopted by most operators, indicates an awareness of the risks involved in operations in a high density environment with limited surveillance resources. This has certainly had a positive effect on reducing NMAC's. Another important aspect, however, may also underlie the low reporting rate. That is, quite simply, a reluctance on the part of pilots to report NMAC's outside of their own community. Since much of the conflicting traffic is likely to be other helicopters from the same operator, little is to be gained by reporting incidents outside their normal operational channels. Such incidents can normally be assessed and corrective actions instituted in-house without the reliance upon outside agencies such as the FAA and NASA. This conclusion is born out to a degree by the responses given by offshore pilots to the questions concerning their frequency of NMAC in the previous 6 months. An NMAC was defined as incident in which an intruding aircraft approached within 1000 feet, and which required an evasive maneuver to avoid a collision or in which no opportunity for evasive action was available. The four operator groups responded as follows:

Group	Frequency (NMAC/6 months)
● Corporate/Executive	1.76
● Offshore	1.64
● Public Service	1.58
● Commercial	1.15
● ALL	1.46

As can be seen, the offshore pilots' experience, based upon a limited sample size, is virtually indistinguishable from both corporate and public service experience, yet over 12% greater than the mean for all responses. This is a further indication that NMAC experience of offshore operators is not unlike that experienced by other types of operators, and its apparent low incidence of NMAC is, at least in part, a by product of under-reporting of the incidents.

While there does not appear to be a significant relationship between reported NMAC and operator type, it would appear that a correlation does exist between the area of operations and frequency of NMAC encounters when assessed on a geographical basis. Some areas are clearly more susceptible to NMACs than others. The following shows NMAC frequency for various geographical regions, based on pilot questionnaire responses:

Region	Frequency (NMAC/6 Months)
LA Basin	1.89
South Florida	1.50
Western U.S.	1.50
Gulf of Mexico	1.47
Appalachia	1.38
Central U.S.	.75
ALL	1.46

It is significant to note that in those regions where helicopter activity is particularly dense, such as Los Angeles, the Gulf Coast of Mexico (Houston to Houma) and Appalachia, respondents to the survey were nearly three times as likely to cite a helicopter as the encounter aircraft in their most recent NMAC.

Region	% Helicopter Encounter	
● Gulf Region	45%	
● LA Basin	33%	37%
● Appalachia	33%	
● Central U.S.	20%	
● South Florida	20%	13%
● Western U.S.	0%	

Arraying the same NMAC data according to operator type presents a less obvious picture, inasmuch as only offshore operators (principally from the Gulf Coast) show a marked deviation from the other operators. This is clearly shown in the following table:

Operator Type	% Helicopter Encounters
● Offshore	55%
● Corporate/Executive	22%
● Commercial	20%
● Public Service	15%
● ALL	23.9%

It appears therefore, that with the exception of offshore pilots, whose operations expose them to an inordinate level of helicopter only traffic, that helicopter/helicopter NMAC exposure is not dependent upon mission type, but rather on the density of other helicopters operating within a particular region. Furthermore, the degree to which the rotorcraft-rotorcraft NMAC risk has been reported in the past (3 helicopter-helicopter NMAC out of 187 reported helicopter NMAC) [Ref 2] is certainly understated. According to this survey, nearly one quarter of the pilot's most recent NMAC involved other helicopters.

3.3.2 Airborne Encounters

In order to support the development of software algorithms capable of providing NMAC protection for helicopters, it is necessary to gain an insight into the various attributes of previous helicopter NMACs. From an analysis of these attributes, recommendations can be made regarding specific operational requirements for a helicopter TCAS.

3.3.2.1 Magnitude

As previously discussed, the rate at which pilots are encountering Near Mid-Air Collisions is approximately 1.5 per 6 months. These pilots will fly, on average, approximately 400 hours per year[3]. We can project, therefore, an average NMAC rate of 7.3 NMAC/1,000 flying hours. Since approximately 2.5 million hours will be flown per year, one might expect to see over 18,000 NMAC's per year, or 73,000 in four years. This certainly bears no resemblance to the 187 helicopter NMAC's reported to NASA during the four year period from 1978 to 1982. Obviously, the NASA data represents only the of the iceberg as far as all NMAC's are concerned. It is quite probable that many of the NMACs recollected by the pilots in the survey did not produce the same level of apprehension for the pilots as did the ones subsequently reported to NASA. However, it remains that the hazard is probably a much more significant threat to helicopters, and aviation in general, than can be supported by NASA's voluntarily reported statistics.

There exists in the helicopter community some dispute regarding FAA flying hour reporting techniques and the flight hour estimates derived from those techniques. FAA estimates are used in this report for the purposes of uniformity since this is an FAA sponsored survey. A more commonly accepted (amongst manufacturers and helicopter operator groups) estimate of annual flight hours is 1.7 million hours. If true, reports of NMAC's should approach 13,750 per year, or 51,00 during a 4 year period. Again, these values exceed, by several orders of magnitude, the number actually reported during the period, and it remains, that regardless of the flight hour reporting techniques employed, Near Mid-Air Collisions are vastly under-reported.

3.3.2.2 Flight Mode

Despite a great deal of diversity in the various mission profiles for corporate, commercial, offshore and public service operators, all groups consistently cited the same operating mode for both their aircraft and the encounter aircraft in their most recent near mid-air collision. For all those surveyed, 73% were flying straight and level at the time of the encounter. Furthermore, over 56% of the encounter aircraft in the NMAC were also flying straight and level at the time. This fact is not as surprising as it seems, since the vast majority of flight time for all flights - rotorcraft, general aviation or air carrier - are performed in the cruise or straight and level mode. Table 3.4 lists the survey responses for all pilots for both their aircraft and the encounter aircraft. As can be seen, over 88% of the respondents were in straight flight (level, climb, or descent) and 79% of the encounter aircraft were in the same mode. Significantly, the pilots were nearly 2.5 times more likely to have had a NMAC while performing a left turn than a right turn. This is probably attributed to the improved visibility helicopter pilots have to the right side, owing to the peculiar arrangement of the pilot seat being on the right (vs airplane pilot seat on left side). For helicopters, the impact of a climb or descent appears to be neutral, probably due to the generally good vertical visibility offered by most helicopter cockpit designs.

As stated previously the majority (approximately 80%) of all helicopter NMAC's involve both a helicopter and a fixed-wing aircraft. While the helicopter pilots surveyed were quick to attribute this fact to inattention and inexperience on the part of their G.A. counterparts, in all fairness this is probably not the main reason. Whereas helicopter pilots enjoy excellent all around visibility, the fixed-wing pilot has his forward-down visibility obstructed by the engine cowl and fuselage. Sideward-downward or sideward-upward visibility is extremely reduced due to the presence of the aircraft wing. This is particularly true in high wing single engine airplanes, such as the Cessna 172, where a turn in either direction presents the pilot with an excellent view of the underside of his wing. In light of this, the results of the survey regarding the encounter aircraft actions leading to the NMAC are predictable. Again, the majority (79%) of the encounter aircraft were straight and level at the time of the encounter. Seven (7) of the respondents stated that the encounter aircraft was in a left turn and six (6) of the encounter aircraft were in a right turn. This indicates that the pilot seating (on the left) for airplanes has less of a negative effect on lateral visibility than the blind spots, produced by the wing. Involvement in NMAC's by fixed-wing aircraft seems not to be dependent on the direction of turn by the aircraft, but instead dependent on the turn alone. Since the low or high wing G.A. aircraft has excellent forward-up visibility, it could be expected that fewer of the reported NMAC's would

Table 3.4 Reported Mode of Flight During Most Recent NMAC

		Climb	Descent	Level	%
Own A/C	Left Turn	1	1	3	8.2%
	Right Turn	1	–	1	3.3%
	Straight	3	6	45	88.5%
	% of Total	8.2%	11.5%	80.3%	
		Climb	Descent	Level	%
Encounter A/C	Left turn	1	3	3	11.5%
	Right Turn	3	1	2	9.8%
	Straight	4	10	34	78.7%
	% of Total	13.1%	23.0%	63.9%	

involve an aircraft climbing towards the reporting helicopter. In fact, the G.A. aircraft was 2 times as likely to be descending towards the helicopter than climbing towards it. The total number of aircraft climbing (straight, right and left) towards the helicopter accounted for only 13% of all reported encounters. Descents were cited in 23% of the encounters, and in 64%, the encounter aircraft was flying level.

The implications of these data on TCAS software design and hardware requirements are significant. Since both aircraft in an NMAC are likely to be in straight and level flight at the time of an encounter, it may not be necessary to provide different TCAS capabilities for various classes of aircraft. In the case of helicopters, a TCAS developed for that class, may also be transferable to fixed-wing general aviation aircraft, which account for over 80% of all helicopter NMAC encounters.

3.3.2.3 Airspeed

The helicopter pilots surveyed exhibited a wide variation in reported airspeeds at the time of their most recent near mid-air collision. This variation is largely attributable to the make of the helicopter flown at the time, and also, to a lesser degree, the mission in which they were involved. The public service pilots surveyed, comprised mainly of law enforcement helicopter pilots, flying primarily Bell 47s, Hughes 269s and Hughes 300s, a reciprocating engine powered helicopter with a maximum V_{NE} (Velocity never exceed) in the range of 60-70 knots. Their primary mission - aerial patrol - often involves orbiting a fixed location on the ground at a fairly low airspeed and at a moderate to high bank angle. The mean airspeed cited by these pilots at the time of their most recent NMAC was 66 knots.

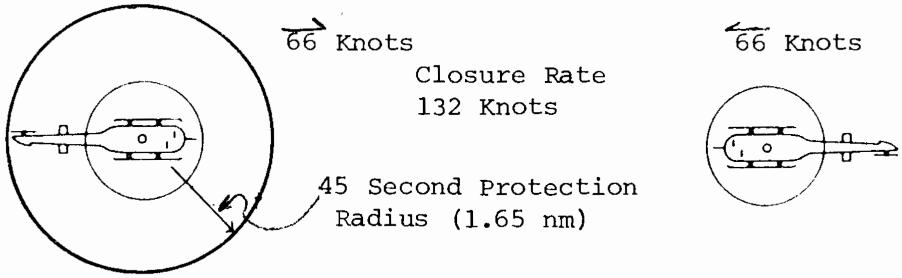
Commercial pilots rank next in terms of the slowest airspeeds at the time of the encounter. Their equipment ranges from the relatively slow Bell 47 to the four bladed turbine helicopter, the S-76. The majority, 55% of the pilots, fly Bell 206 variants, with a V_{NE} of 120 knots and cruise airspeed of 90 knots. Little can be determined regarding their mission at the time of the encounter since the mission profiles of this particular operator group are extremely diverse. However, the mean airspeed at the time of this encounter was 87.6 knots, very near the cruise airspeed of the most widely used helicopter by the group.

Corporate pilots evidenced a somewhat higher encounter airspeed, again a function of the mix of helicopter types principally used by the group. A preponderance of Bell 206 variants, with a significant number of 3-4 bladed turbine helicopters raised the mean encounter airspeed for this group to 103 knots. The primary mission cited by this group, VIP transportation, consists primarily of smooth climbs and descents at or near the suggested cruise airspeed and an enroute segment at the suggested airspeed.

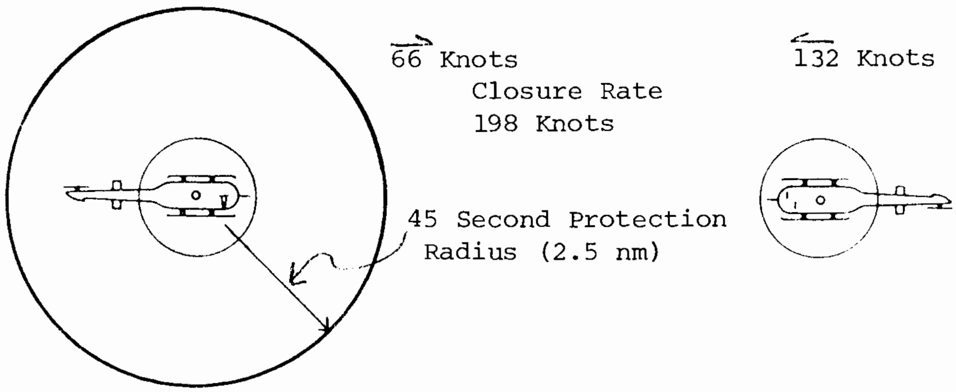
Finally, the offshore pilots exhibited the highest average encounter airspeed. Their mission profile in not unlike that of the corporate pilots, so the main difference in the mean airspeed of the two groups is a direct result of the equipment mix of the two groups of operators. The preponderance of fast 3-4 bladed helicopters, principally Sikorsky S-76s used by this group, with a low number of Bell 206's, and Bell 205's, raises the average encounter speed to 117 knots for the group.

The reported encounter airspeed is important since it is one component in the determination of closure rate of two conflicting aircraft, that closure rate being a function of airspeed and angles of incidence of the two aircraft. But more importantly, encounter airspeed of the involved helicopter has a tremendous impact on the size of the volume of air (read coverage radius of the beacon signals) to be protected by the TCAS. Figures 3.4a to 3.4c graphically depicts the importance of this data. Figure 3.4a depicts an encounter of two low speed helicopters in their most critical conflict situation (in terms of closure rate). Assuming that, as with the TCAS II developed for air carrier operators, separation time rather than separation distance is the critical coverage parameter, and assuming that a 45 second advance collision warning is desired, the beacon signal strength need only require transmission of 1.65nm. Figure 3.4b depicts a head on encounter between two helicopters with a combined closure rate of 198 knots. A coverage volume of 2.48nm in radius could provide the necessary 45 seconds advanced warning. Finally, a worst case scenario involving a high speed helicopter (132 knots) and a low altitude military jet (250 knots) on a head on collision course is shown in figure 3.4c. In this event, a coverage volume of 4.8nm in radius would provide the 45 second advanced collision warning. It should be noted that the incidence of this last case is low nationally, although on a regional basis, the Appalachian Region, ranging from North Georgia to Pennsylvania accounts for over 65% of this type of NMAC that are reported to NASA. One possible explanation of this fact, and the fact that the military training route hazard represents such a large (12.3%) part of all NASA helicopter NMAC statistics may lie in the fact that a much larger percentage of the helicopter-military NMAC's are being reported more regularly. During the on-site discussions with members of the Appalachian Helicopter Pilots' Association, they expressed their concern over the hazards represented by this type of encounter. Furthermore they were mobilized as a group to report these incidents in order that systems changes could be developed and instituted to eliminate or reduce the problem. Another unsubstantiated conclusion can be drawn since military operations are easily distinguishable across a largely unidentifiable backdrop of civil operations, a report against a military operator is far more likely to return to the object of the complaint than one made against an obscure, uncontrolled general aviation aircraft. This is not to minimize the hazard incident to these low level, high speed, encounters, but rather to mitigate against the high reported rate of these incidents in general.

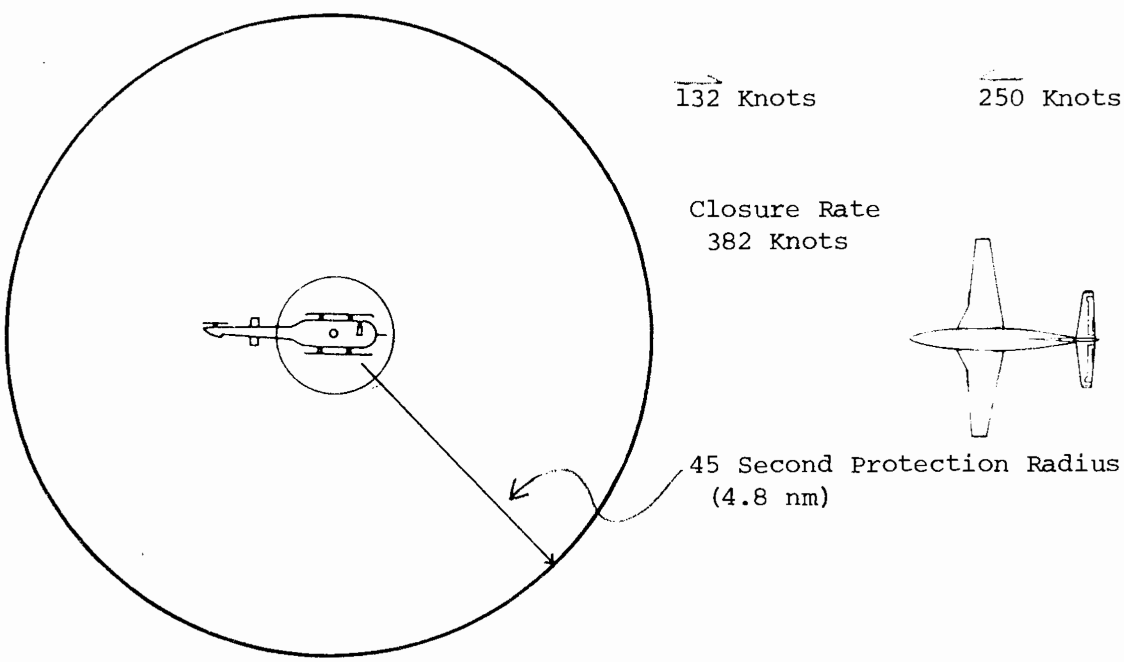
As shown in Figures 3.4a to 3.4c, the coverage volume necessary to assure the 45 second advanced warning ranges from 1.65nm for the least hazardous head on encounter to 4.8nm for the same warning in the worst case. Also, as evidenced by the reported airspeeds for each of the operator groups, differing protection radii could be anticipated for the same warning period. It is interesting that the pilots, although some are not aware of the mathematical correlation between operating airspeeds and protection radii, desired increasing coverage radii as their airspeeds increased. Table 3.5 lists the mean reported airspeed at the time of their most recent encounter and the mean desired coverage radius for each of the groups. Encouragingly, the average responses for all the groups, as well as the average for the population as a whole, falls generally within the range anticipated for the best and worse case scenarios, with the exception that the offshore pilots expressed a



a. Best Case - 2 Low Speed Helicopters



b. Medium Case - Low Speed and High Speed Helicopters



c. Worst Case - High Speed Helicopter and Low Altitude Military Jet

Figure 3.4 Airspace Protection Radius as a Function of Closure Rate

Table 3.5 Reported Encounter Airspeed and Desired Coverage Radius by Operator Group

Operator Group	Average Encounter Airspeed	Mean Desired Coverage Radius	45 Sec Coverage Radius*
Public Service	66 knots	2.46nm	2.48
Commercial	88 knots	2.7nm	2.75
Corporate/Executive	103 knots	3.5nm	2.94
Offshore	117 knots	5.08nm	3.11

*Head-on encounter w/132 knot aircraft

desire for a somewhat (63%) larger radius of protection. One possible explanation for this fact is that offshore pilots, with their relatively long enroute legs and predictable headings, can use the longer lead time more effectively than operators coping with numerous heading changes. In short, a conflict predicted at 5 miles is more likely to remain a conflict as time passes for the offshore operators than for commercial operators engaging in various utility missions, and public service helicopters engaged in low level surveillance.

3.3.2.4 Altitude

The altitude at which helicopters operate, and the altitudes at which they encounter the most conflicting air traffic is significant since it determines, to a certain degree, the latitude within which a helicopter TCAS can provide conflict resolution advisories. As with the other parameters previously discussed, operating altitude appears to be broadly predictable along the line of operator type. Three questions were asked (#5, #42, #43) to determine the altitude at which the pilots experienced their most recent near mid-air collision, their most common operating altitude, and the altitude at which they experience the most conflicting air traffic. The survey responses for each of the operator groups are shown in Tables 3.6, 3.7 and 3.8.

The most important conclusion which may be drawn from these data is that the low altitude at which most helicopters operate, regardless of their operator grouping, may preclude the use of, or at least dependence upon, vertical conflict resolution advisories as a means of resolving collision conflicts. Even with a well calibrated radar altimeter which provides absolute altitude above the ground, their would always remain the possibility that a decisive vertical advisory such as "Descend † 750

Table 3.6 Mean Operating Altitude

Operator	Altitude (AGL)
Public Service	785 feet
Commercial	863 feet
Corporate	1203 feet
Offshore	1553 feet

Table 3.7 Mean Encounter Altitude

Operator	Altitude (AGL)
Public Service	617 feet
Commercial	744 feet
Offshore	980 feet
Corporate	1508 feet

Table 3.8 Mean Conflicting Traffic Altitude

Operator	Altitude (AGL)
Offshore	821 feet
Public Service	1071 feet
Commercial	1250 feet
Corporate	1265 feet

feet per minute, NOW" could result in bringing the helicopter in contact with objects not sensed by the radar, such as power lines, antennas or tall buildings.

While a "descend" advisory has obvious inherent limitations and liabilities, it should be noted that a "climb" advisory is attended by several non-negligible limitations. At the present time, a significant number, in fact, the majority of helicopters are neither equipped nor certified for IFR flight. Additionally, a large number of pilots are not certified for flight into instrument meteorological conditions. Remember that one of the advantages of helicopters is that their slow speed and maneuverability allow them to operate under VFR and Special VFR with both reduced visibility and low ceilings (1000 feet ceiling and 3 miles for visual metorological conditions in controlled airspace). During a flight in such conditions at an altitude of 500 feet, a "climb" advisory, while obviating a ground or mid-air collision, could well force a penetration into instrument conditions. The result of such an encounter could well be fatal, since inadvertent IMC penetration is currently one of the leading causes of helicopter pilot error accidents, particularly for single pilot operations. Thus, dependence upon vertical conflict resolution as is currently employed in the air carrier type TCAS II, is probably not appropriate for the helicopter version of TCAS, since either a descent or climb advisory may in many circumstances have attendant to it unacceptable risks.

3.3.2.5 Pilot Preferred Escape Manuevers

In order for the TCAS to fulfill its function of avoiding mid-air collisions, it should provide as a minimum, accurate conflict alert data to the pilot. This alert data may take many forms, but regardless of its form, it must provide sufficient data for the pilot to decide his own course of action. If resolutions are to be provided, the credibility of the resolution advisory will be largely based upon how well it coincides with the pilots own preferred actions. Since many mid-air collisions can be avoided only through immediate actions on the part of a pilot, hesitation induced by an internal conflict between pilot and computer could have disastrous effects. To minimize this possibility, TCAS logic should, where practicable, take into account historic pilot avoidance manuever preferences and present resolutions likely to be accepted by pilots without hesitation. This subject, historical manuever preferences, is addressed by question #13 of the survey. The question is intentionally contrived so as to elicit a "knee jerk" response from the subject, rather than providing any situational data from which the pilot could logically arrive at a "correct" avoidance manuever. Since a resolution advisory which is concurrent with a pilot's instinctual response is most apt to be readily implemented by the pilot, these data should play an important role in software development for conflict resolution advisories.

The pilots surveyed were asked whether or not they most frequently maneuvered vertically, horizontally, longitudinally or in a combination of the three to avoid conflicting traffic. The responses for each operator group are shown in Figures 3.5a to 3.5d. As can be seen, in nearly all circumstances, pilots prefer a combination of horizontal and vertical maneuvers to avoid the collisions. By examining only the aggregate raw numbers, as shown in Figure 3.6, their seems to be little significant difference in their preference for a vertical or horizontal avoidance maneuver. However, a case can be made that the operative variable in avoidance maneuver selection is not based upon operator grouping but rather on their most commonly flown altitude. The public service pilots, for example, exhibits a very noticeable preference for the horizontal maneuver over all others. This group also cited the lowest mean NMAC encounter operating altitude (617 Ft Agl) and the smallest standard deviation about that mean, than any of the other three groups. This indicates that some correlation may exist between operating altitude and preference for an avoidance maneuver.

In order to further investigate this correlation, the preference data was re-evaluated against the pilots' normal operating altitudes. Figures 3.7a to 3.7c illustrate the results. The altitude slices shown, 0-500, 500-1000 and 1000-1500 Ft AGL, represent the vast majority (89%) of the operating altitude cited by the pilots, and each altitude slice accounts for a minimum of 13% of all responses. Thus, these data are probably more representative of "nature" than any similar slicing that could be taken. The remaining slices are of little significance since the size of those samples would be extremely limited.

The figures demonstrate rather well the extent to which preferences change depending on operating altitude. For the first slice, 0-500 Ft AGL, pilots were twice as likely to prefer a horizontal versus vertical avoidance maneuver. As the operating altitude is increased to 500-1000 feet, it was found that the percentage of pilots preferring a horizontal move declined to 36%, while those preferring a vertical escape remained constant. Finally between 1000-1500 FT AGL, those preferring a turn declined to less than half of those preferring a climb or descent. Notably, for these three altitude slices, little change was evidenced in the percentage of those preferring a vertical maneuver (22%, 21% and 25% respectively). The greatest movement was between the horizontal and combination categories. Therefore it appears that as more separation between the ground was obtained, the more pilots felt they had greater leeway in their selection of avoidance maneuvers. It should be noted that for all those who selected a combination of maneuvers, horizontal maneuvering was included in all (100%) of those responses.

These data again indicate that the resolution advisories which suggest or recommend only vertical escape maneuvers may not produce the level of pilot acceptance and the immediacy of pilot response necessary to avoid a mid-air collision, at least in the low altitude flight regime where helicopters tend to operate.

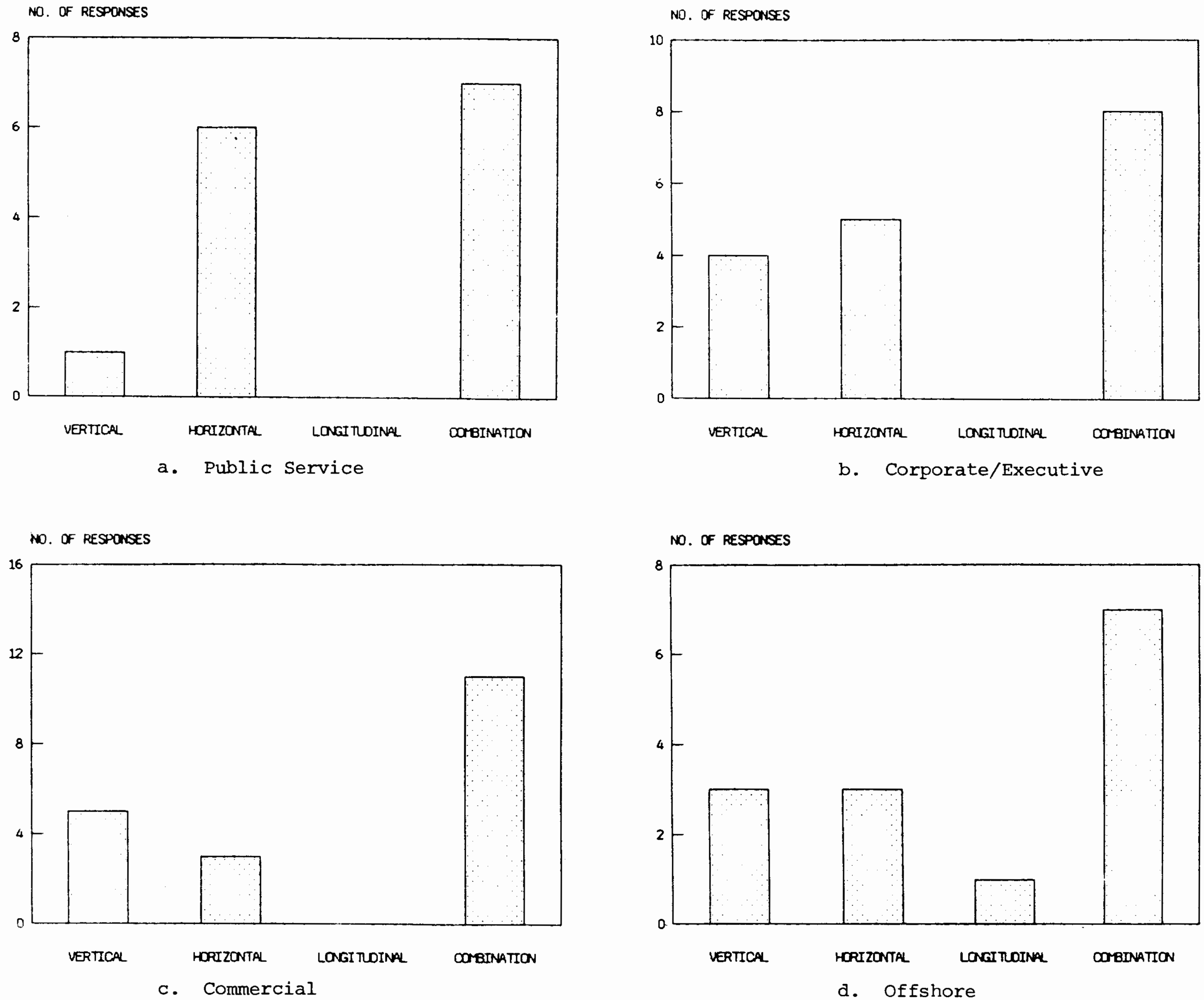


Figure 3.5 Pilot Preferred Avoidance Maneuvers

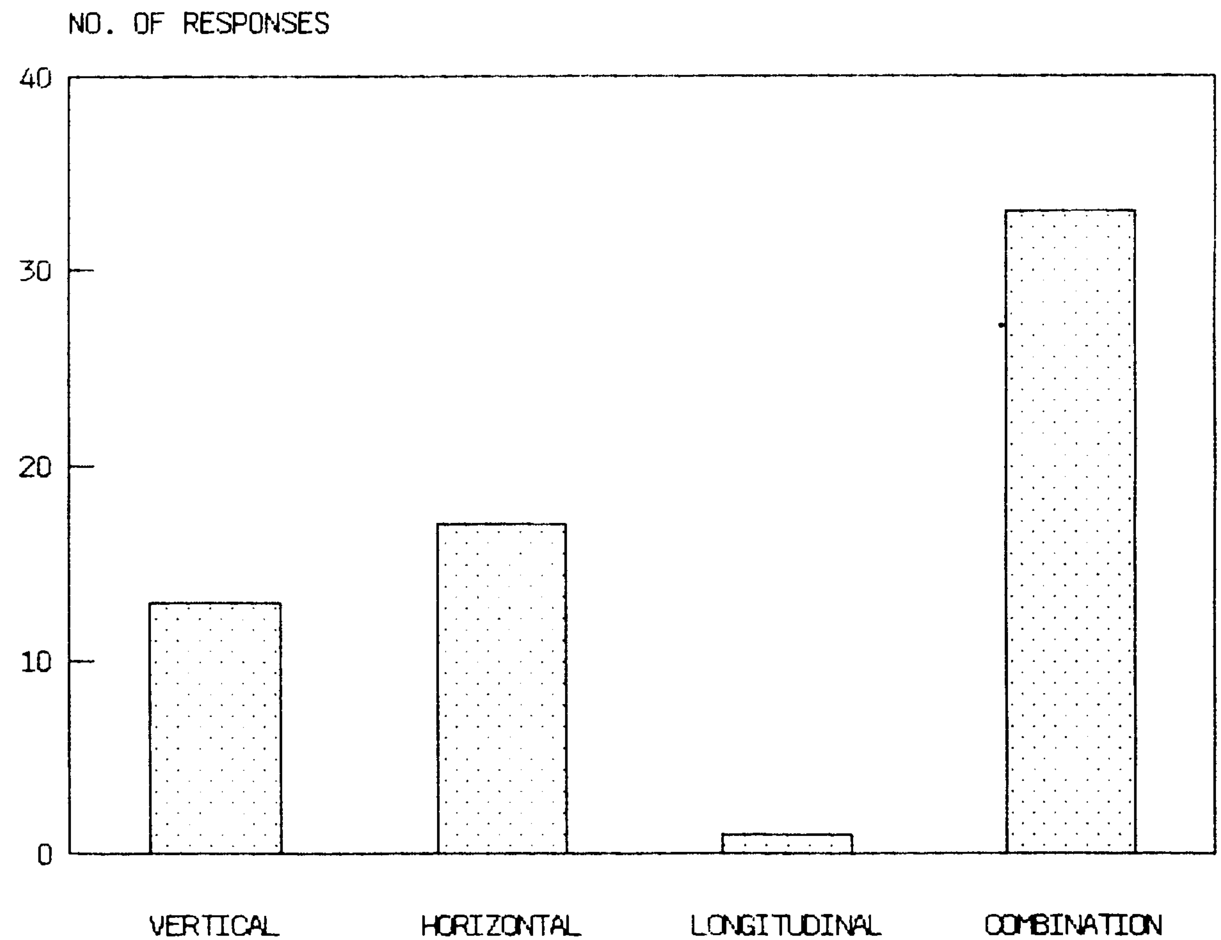
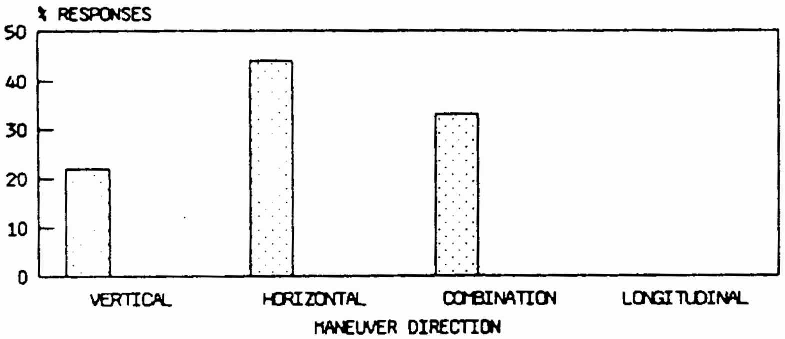
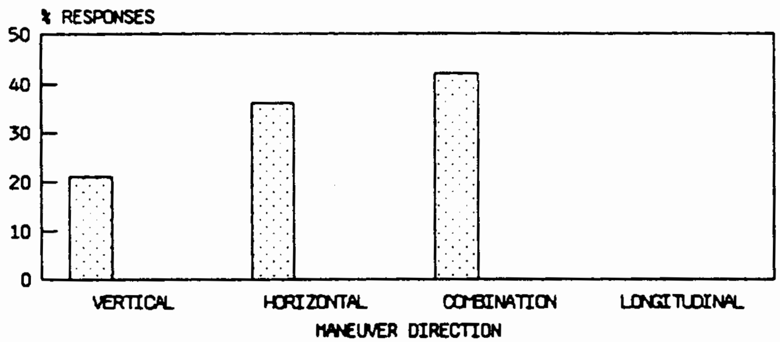


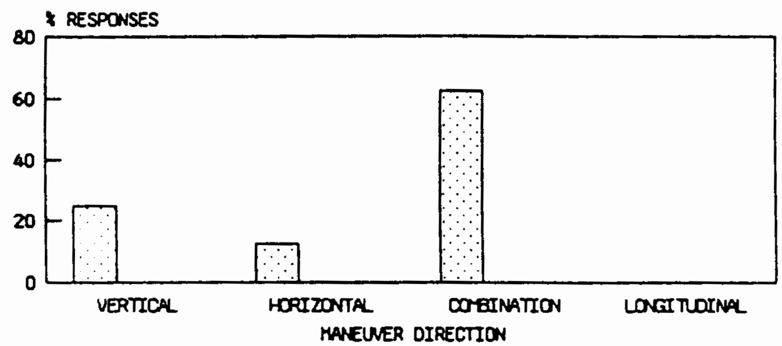
Figure 3.6 Pilot Preferred Avoidance Maneuvers
(Composite)



a. Operating Altitude 500 FT. AGL



b. Operating Altitude between 500 and 1000 FT AGL



c. Operating Altitude between 1000 and 1500 FT AGL

Figure 3.7 Pilot Preferred Avoidance Manouver By Operating Altitude

3.3.2.6 Critical Quadrant

The critical quadrant can best be described as that quadrant, relative to the pilots seating, which, when occupied by a conflicting/converging aircraft, affords the least reaction time for the pilot to initiate an evasive maneuver. Over 75% of all respondents cited either the left or rear quadrant as the most critical quadrant, with 6 multiple responses indicating both left and rear quadrants . This is at odds with the data derived from the textual descriptions of the pilots' most recent NMAC's, in which encounters in the left front and right quadrants were cited most frequently by the pilots. However in the single instance in which the pilot described an actual mid-air collision rather than an NMAC, the respondent described being tail-ended by an approaching light airplane.

The "Survey of Characteristics of Near Mid-Air Collisions Involving Helicopters"[2] presents data which would seem to suggest that the critical quadrant for NMAC is the forward quadrant (11,12 and 1 o'clock positions), since 43.5% of all NMAC's in which the intruder position was reported occurred in that quadrant. Figure 3.8 presents a breakdown of reported NMAC's by quadrant. The assumption that the front quadrant is the most critical, based upon past experience, is misleading, since it ignores the fact that pilot vision is directed primarily in the forward quadrant and he is therefore far more likely to detect an intruder there than in any other quadrant. It follows from this that he would be least likely to detect an intruder in the rear quadrant. This is not the case, however, as is shown in Figure 3.8. Despite the limited visibility in that direction, the rear quadrant accounts for 21.3% of reported NMACs.

There are two possible interpretations of these data. One is that pilots are concerned with traffic in this quadrant and therefor devote a significant portion of their traffic scan in that direction. The other possibility is that because the rear quadrant is largely unmonitored by the normal traffic scan, a higher percentage of aircraft entering that quadrant eventually pose an NMAC threat since they are allowed to close with the helicopter to a closer approach distance before they are detected, requiring an evasive maneuver more often than aircraft approaching from any other quadrant.

Thus, pilot narratives describing NMAC's in the forward quadrant are consistent with the findings of Reference 2. Likewise, pilot concern for activity in the left-rear and rear quadrants is supported by those findings.

As discussed earlier, rearward visibility, already reduced by the pilots seating arrangement, accounts for at least a part of the pilots concern over activity in that quadrant. That concern is exacerbated by the helicopter's low airspeed. In nearly all encounters with a fixed-wing airplane, the helicopter will normally be the slower of the two. Thus, whereas a helicopter is unlikely to overtake most fixed-wing

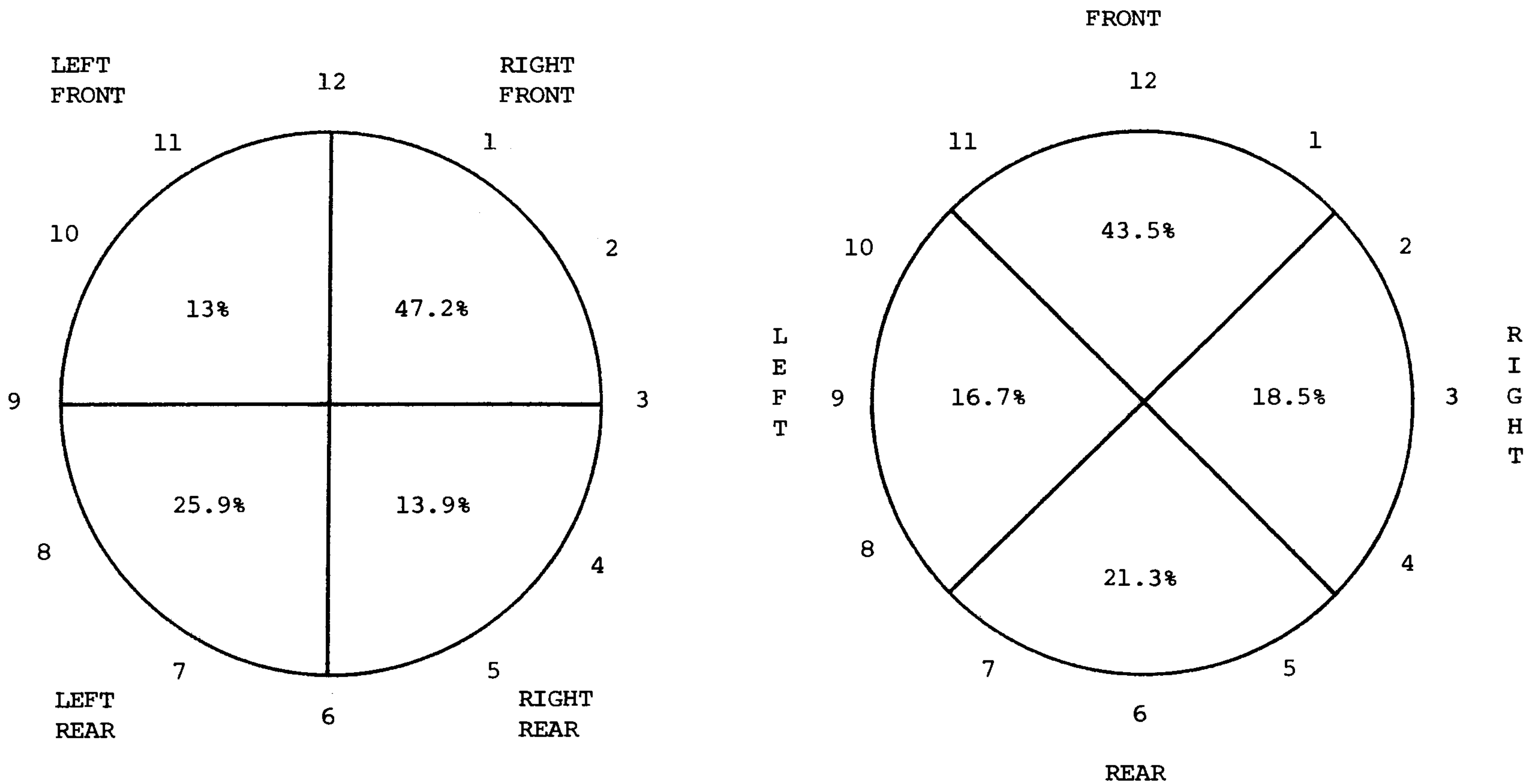


Figure 3.8 Distribution of Reported Intruder Positions by Quadrant

airplanes from the rear quadrants, the potential for airplanes to do this is great, especially in the event that the airplane is descending (with its inherently reduced downward visibility).

A positive aspect of an encounter from this quadrant is that a beacon transmitter sized for the worst case scenario (head on) would provide a longer advanced warning than for the head on encounter. To use an example consider the case of a head on collision course between two slow helicopters, as in Figure 3.9. The combined closure rate of the two, 132 knots, will require a minimum 1.65 nautical mile coverage radius to insure a 45 second advanced warning. If the same helicopter traveling at 66 knots was on a converging course with an overtaking general aviation airplane or helicopter traveling at 132 knots, the 45 second advanced warning would be increased to 90 seconds, because of the lower closure rate.

3.3.2.7 Radio Signal "Dead Zones"

In order to insure that the TCAS beacon's interrogation signal coverage is maximized and that interrogation replies are widely received, the beacon antennas must be located to minimize transmission and reception dead zones. Question #9 to #11 address the helicopter's susceptibility to dead zones, as well as the susceptibility of various transmitters and receivers to the dead zones.

Of 64 pilots who responded to the series of questions, 62.5% (40) reported that their equipment did not demonstrate any noticeable dead zones in any phase of flight or for any particular piece of navigation or communications equipment. Another 23.4% (15) of the surveyees, after first saying no, they did not exhibit any "dead zones", preceded to list equipment which might be susceptible. The remaining 14% (9) reported dead zones and listed both the phase of flight, (turning, climbing, straight and level, etc), and the equipment affected.

Since antenna configuration and placement is similar for each helicopter type, the affirmative responses (those citing dead zones) were grouped according to helicopter type. It was hoped that some trend might be uncovered by such an analysis. This was not the case. S-76 and Bell 206's, which account for 56% of all equipment used by the sample population, accounted for 55% of the population which cited dead zones. The remaining 4 (44%) affirmative responses were drawn from pilots using Bell 205, Hughes 269, Hughes 300, and Aerospatiale AS355 helicopters (1 each). This group accounts for 14% of the sample at large, but the percentage difference is not significant since the remaining 28 aircraft that are not Bell 206's or Sikorsky S-76's are distributed among 13 other helicopter types.

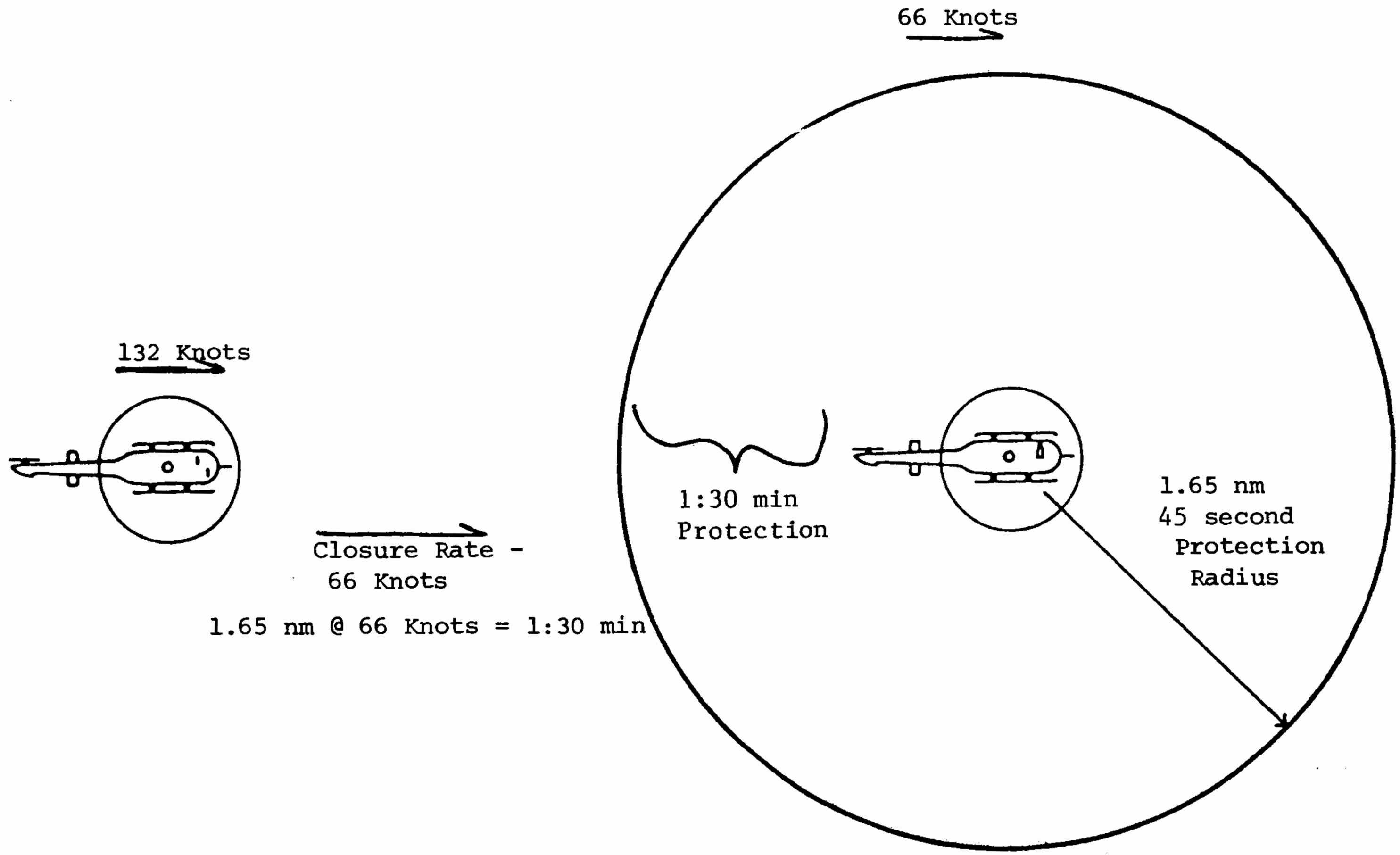


Figure 3.9 Increased Reaction Time in Critical Quadrant Intrusions

A look at the radio types and phases of flight cited to exhibit dead zones is no more illuminating. Table 3.9 shows a matrix of cited equipment and the phase of flight for which it was cited. Clearly VHF radios are cited most frequently as exhibiting dead zones, yet it should be noted that VHF radio is essentially an entry item into the airspace system, thus all users polled have them. Moreover, VHF radios are constantly in use and any anomaly would be detected. Eight users suggested that VOR equipment exhibited dead zones, but again, VOR's are the most commonly used navigation radio, making it difficult, given the smallness of the sample size, to draw any definitive conclusions.

Finally, assessing the impact of "phase of flight" on the tendency for dead zones, it would appear that the susceptibility is not linked to any particular operating mode, although its incidence in climbs is reported the least. In fact the single report of dead zones in a climb was elicited from a pilot who said his VHF radio exhibited the dead zones in all phases of flight. In this particular case, the problem was probably due to maintenance rather than any inherent limitation induced by his antenna positioning.

For the same reason that no particular significance can be assigned to the fact that all respondents who indicated that they had dead zones cited VHF COM dead zones, it may be significant that transponders (MODE A, MODE C) were not cited. They too are airspace entry equipment and nearly all (91%) of the aircraft were so equipped. Transponder antennas are normally positioned beneath the chin bubble or underneath the fuselage of helicopters, in order to maximize horizontal, longitudinal and vertical (downward) transmission and reception coverage. A case could be made for mounting TCAS antennas on the cabin top and below the fuselage to maximize beacon coverage in all directions. However, such a decision must follow a careful analysis of the effect main rotor blade modulation would have on the TCAS's transmitted interrogation signal and the subsequent reply.

It is also possible that transponder dead zones are equally or nearly as recurrent as other radio transceivers, and that the lack of reports are due to the fact that most VFR pilots turn them on and forget them. An intermittent dead zone for the transponder antenna would only be noticed if a pilot were advised that ATC was not able to receive a reply from his transponder. Since the transponder does not broadcast continuously and responds only to an ATCRB interrogation several interrogation/reply cycles could elapse, during which time the conditions causing the intermittent dead zones could be rectified and no ATC advisory would be made. This aspect of transponder antenna functioning must also be addressed before a decision on TCAS antenna mounting is made.

Table 3.9 Avionics Equipment Displaying Dead Zones

Equipment	Climbs	Descents	Straight and Level	Turns Toward Transmitter	Turns Away from Transmitter
VOR		1	1	2	2
VHF	1	2	3	2	2

(number times cited)

3.3.2.8 Significant Factors/Causes of Aerial Traffic Conflicts

In addition to detailing the various mission characteristics and operational profiles which impact the NMAC experience of the pilot groups surveyed, the questionnaire also sought to determine the pilots' own perception of the major causes of, or factors in, aerial traffic conflicts and near mid-air collisions. Question #14 requested that the pilots rank each of 7 possible causes/factors which were predetermined to contribute to the NMAC problem. Figures 3.10 to 3.16 present the results of the tabulation of these responses.

Two conclusions may be readily drawn from a brief glance at the figures. First, pilots consider that traffic operating in their critical quadrant (the left/rear quadrant) is the most significant cause or factor of near mid-air collisions and other aerial traffic encounters. In this regard the sample group is in agreement with nature, inasmuch as of 187 reported NMAC's involving helicopters, over 35% involved aircraft approaching from the critical quadrant.

Also apparent from the figures is that pilots do not to any great extent consider ATC involvement to figure significantly in helicopter NMAC's. Nearly 50% of the respondents considered ATC involvement to be the least important factor or cause. In fact the distribution of responses is nearly exponential as the scale is assessed from most to least important.

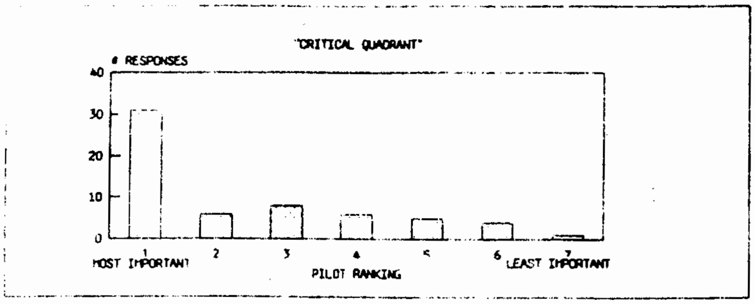


Figure 3.10 Distribution of Pilot Rankings - Critical Quadrant

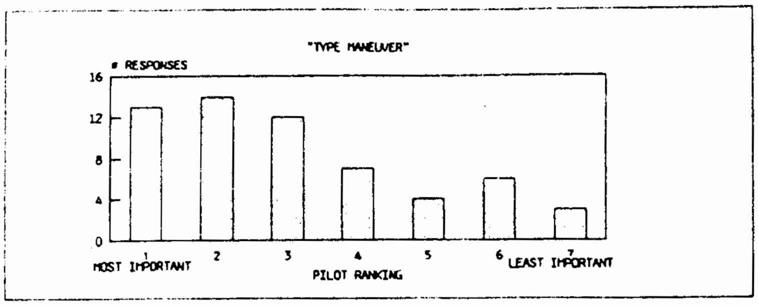


Figure 3.11 Distribution of Pilot Rankings - Type Maneuver

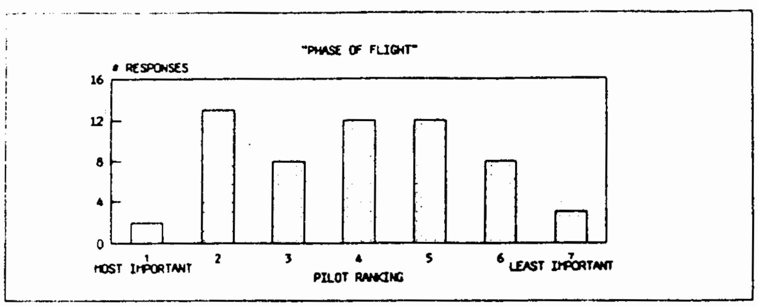


Figure 3.12 Distribution of Pilot Rankings - Phase of Flight

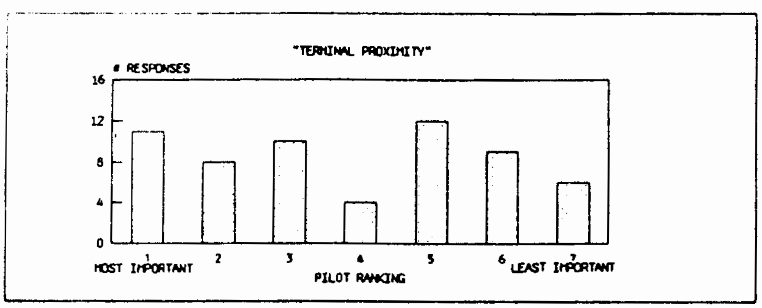


Figure 3.13 Distribution of Pilot Rankings - Terminal Proximity

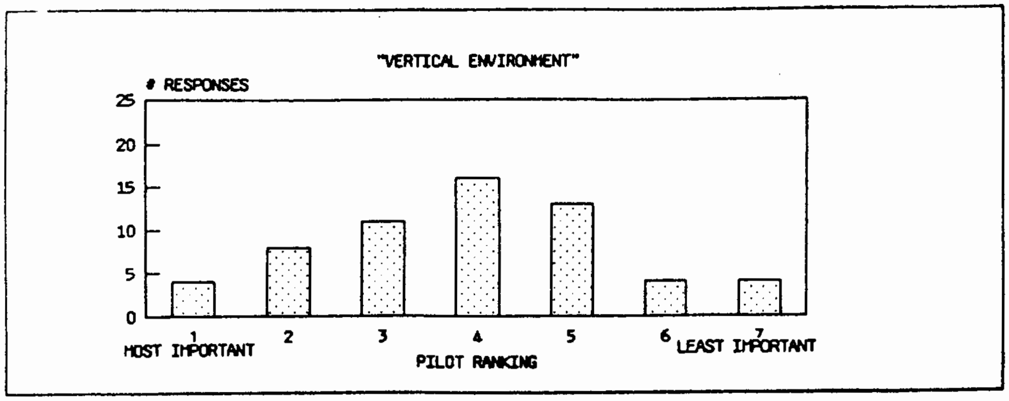


Figure 3.14 Distribution of Pilot Rankings - Vertial Environment

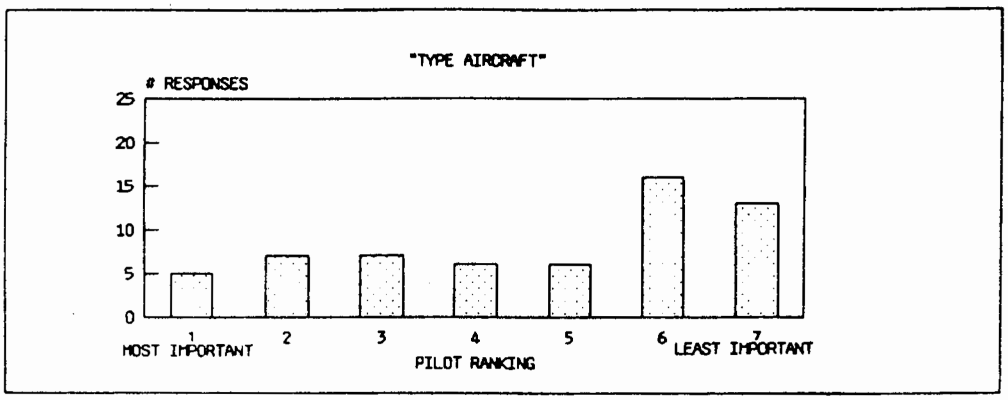


Figure 3.15 Distribution of Pilot Rankings - Type Aircraft

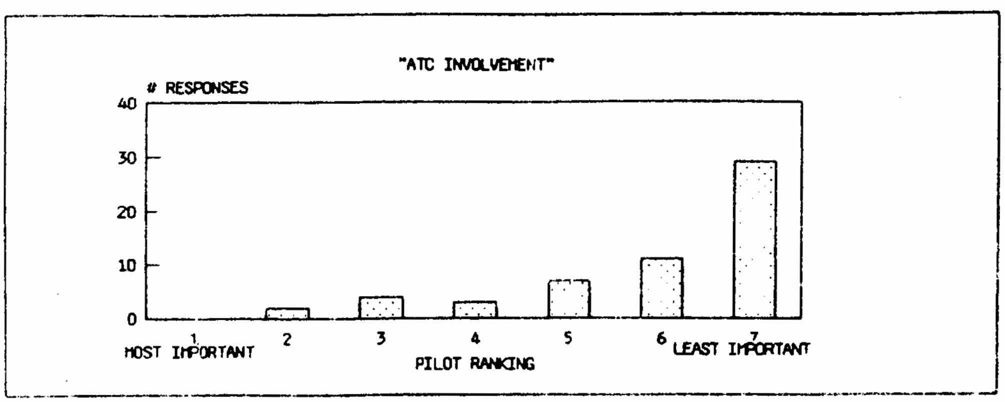


Figure 3.16 Distribution of Pilot Rankings - ATC Involvement

Beyond these initial findings, the data remains inconclusive. For example, Item #14g "Terminal Proximity" drew responses strikingly dissimilar to the other 6 cause/factors. The data appears to be bi-modal, with the modes centering near 2 (very important) and 6 (very unimportant) on the ranking scale, with only 4 respondents ranking terminal proximity as neutral. The conventional wisdom, and in fact operational experience, shows that the majority of near mid-air collisions occur at or near an airport where aircraft converge for takeoff or landing. Over 40% of all reported helicopter NMAC's have occurred in the vicinity of an airport, heliport or other landing area. As such, the bimodality of the distribution suggests that the term "Terminal Proximity" was misunderstood by the 1/2 of the sample, either those who cited its significance, or more likely, those who stated it was unimportant. For the purposes of this analysis, it is sufficient to state that these data are suspect and having declared it so, apply engineering and pilot judgement to the "good" data. It is believed that if the question were better stated, the factor of terminal proximity would be shown to be very significant.

Surprisingly the most neutral of cause factors was the "Vertical Environment". It is surprising since the sample had previously expressed a reluctance to maneuver vertically as an avoidance maneuver, and because in conversation, their most frequently cited worst case collision scenario involved a fixed-wing aircraft descending towards them from the rear or critical quadrant. However, even in this relatively small sample size, a nearly normal distribution is readily apparent, with the most frequently (27%) cited response being 4, or neutral in the 1 to 7 scale. An equal number of respondents cited it as the most and least important factor (6.7%). Finally the split between those responses in the "important range" (1-3) and in the not important range (5-7) was nearly even at 38% and 35%. Therefore it is determined that as a factor in NMAC and other aerial conflicts, the vertical environment is perceived as neither overwhelmingly important nor unimportant.

The data is skewed quite noticeably as it relates to both "Type of Aircraft" and "Types of Maneuver", although in different directions. In the case of the former, the responses were uniform throughout the range of most important to slightly less unimportant. However nearly 50% (29 of 60 responses) of the respondents ranked it as least important or next to least important. No trend became evident when the data was examined to determine the types of equipment flown by those who responded that aircraft type was the least important. This is unfortunate as it may have pointed to one or more fundamental design characteristics inherent in that aircraft which could mitigate against helicopter NMAC's.

The skewing of data is equally evident for the responses concerning "type of maneuver". Nearly 50% (27 of 59) of the sample felt the the "type of maneuver" was most or very important, with another 12 respondents (20%) stating that it was the third most important factor. An examination of those rated maneuvers, again showed no particular trends which would indicate that a single maneuver was responsible for the skewing.

Finally, "phase of flight" was examined as a cause/factor in NMAC's. With the exception of thirteen responses in which phase of flight was ranked as the second most important factor, the data would appear to be normally distributed about a median centered between 4th and 5th most important. The small sample size could well be responsible for the hump in the curve at "2". However, upon checking the phases of flight cited by those responding that this aspect was the 2nd most important cause factor in NMAC's, an interesting trend was discovered. Eleven of the 13 respondents described a phase of flight. Of these 11, five cited the approach and departure phases as the second most important. The complete breakdown is detailed below:

"Phase of Flight"	Number of Responses
● Approach/Departure	5
● Cruise	2
● VFR Days	1
● Straight Climbs/Descents	1
● Marginal VFR	1
● Busy In Cockpit	1

Only three of these responses should properly be termed a phase of flight, those being approach/departure, cruise and perhaps climbs/descents. The remaining three are flight conditions. The high percentage which described the approach and departure phase as being critical tends to support the conclusion that "Terminal Proximity" is more significant than the raw data suggests, and that the approach and departure phase of flight above is the most critical phase of flight. Had "phase of flight" been reworded as "approach and departure phase," the results may well have shown this to be a significant factor in aerial traffic conflicts.

The question asked for a ranking of the seven factors in order of importance. Based upon the previous discussions our ranking of the results is as follows:

MOST IMPORTANT
- "Critical Quadrant"
- "Type Maneuver"
- "Terminal Proximity"
- "Phase of Flight" (Approach/Dept)
- "Vertical Environment"
- "Type of aircraft"

LEAST IMPORTANT
- "ATC Involvement"

3.3.2.9 TCAS Position Prediction Capability

Part of the uniqueness of the helicopter rests in its high and low speed maneuverability. That capability has made the helicopter the aircraft of choice for a wide range of applications, ranging from police surveillance to cattle herding to electronic newsgathering. Unfortunately it is precisely that maneuverability, particularly horizontal, which presents the greatest challenge to accurately predicting a conflict between a helicopter and an intruding aircraft. Whereas air carrier operations, for which the TCAS II was originally developed, are characterized by long en route (straight) legs, and slow (and few) standard rate heading changes, helicopter operations are far less homogeneous in nature. A goal of the survey was therefore, to determine from the pilots viewpoint which of several helicopter missions exhibited an inordinate amount of heading and altitude changes which could inhibit the TCAS's position prediction capability. Questions #18 - #33 were developed for that purpose. Unfortunately, the respondents had a difficult time answering what amounted to a 3 dimensional matrix of questions. The raw data obtained is presented in Appendix B of this report and may be used as desired. However, no specific conclusions regarding the responses are presented in this report.

The modified Delphi process did however afford the opportunity to address this subject in a purely subjective manner. In discussions with pilot organizations throughout the country, the issue was raised and pilots were requested to describe several of their missions in which frequent and abrupt heading and altitude changes are made, the impact of those maneuvers on TCAS position prediction capability, and the overall collision risk involved when those maneuvers are performed. A synopsis of these discussions is provided in the following paragraphs.

3.3.2.9.1 Police Surveillance

In the normal daily routine of police helicopters operations, pilots are frequently called upon to perform surveillance of an area, person or object. Depending upon the risk that the surveillance will be detected, police pilots use a wide variety of techniques including an orbit of the target area. This particular technique entails nearly constant heading changes, with a wide range of bank angles depending upon how close the pilot needs to stay to the orbit's focus.

The pilot is normally accompanied by a trained observer, whose function is primarily to maintain visual contact with the surveillance target on the ground, while the pilot monitors flight instruments and engine instruments, flies the helicopter, and attempts to visually clear (for other air traffic) the helicopter in the direction of the turn. Unfortunately, when the observer is used, aircraft turns are necessarily made towards the left quadrant, where the pilots vision is obstructed, thereby increasing the likelihood that intruding traffic from the left or left rear (critical) quadrant would not be detected.

The ability of the TCAS to actually predict an encounter in these circumstances is probably very limited. It may be that the best alerting scheme for this situation would entail monitoring of beacon replies from all quadrants and presenting them on a planview display according to their relative distance and bearing from the helicopter. A glance at this display would be incorporated into the pilot's instrument cross check which would alert him to check along the relative bearing for traffic which he believes represents the most imminent threat to his helicopter. A simpler method could employ a lighted quadrant display, overlaid by concentric rings representing distances from the aircraft. The arcs created by this arrangement could be illuminated to indicate the presence of traffic within a specific quadrant (or octant) and within the range represented by the rings. The advantages of such a system are that they do not rely on any inherent conflict prediction schemes at all. However, it is highly dependent on the pilots ability to visually acquire and track the target once alerted by the TCAS, which could become difficult if multiple targets are present within the same sector.

The group suggesting that orbits posed a significant NMAC exposure risk was comprised primarily of law enforcement officers operating in the Los Angeles Basin, and the perception is largely based on not only the mission specific flight profiles but also the high level of air traffic predominant in the region. As such it can be concluded that exposure is high and therefore any TCAS system would contribute greatly to overall safety of their operations.

3.3.2.9.2 Electronic News Gathering (ENG)

The basic mission profile of an ENG mission does not differ a great deal from that described for the surveillance orbit. Nor does the air traffic environment of the ENG helicopter differ from that described for the police orbit, since the economics of the mission generally forces the basing of these aircraft in the large metropolitan and urban areas, where the size of the market can justify the expense of helicopter leasing and purchasing. The electronic news gathering mission presents a new risk which is not normally associated with police surveillance. That is, the news event which precipitates the launching of the ENG helicopter, can in many cases be the focus of other air traffic in the vicinity. That traffic may include law enforcement, emergency medical services or disaster relief missions in the event of a natural or manmade disaster, and sightseers, photography aircraft, other ENG helicopters and assorted other onlookers in the case of sporting events or other newsworthy gatherings. Thus, in some circumstances, the ENG mission may entail a greater exposure to the mid-air collision risk than the police surveillance mission, with no significant changes in the mission profiles which would make positive prediction (and therefore conflict alerting) any easier a task. However, given the high level of risk, a TCAS system such as described previously could still provide a reasonable improvement in collision avoidance over the current "see and avoid" dictum under which the missions are currently performed.

3.3.2.9.3 Aerial Application, Herding and Forestry

Aerial application, herding and forestry are performed primarily in sparsely populated rural areas, and as such, need not contend with the volume of traffic that are encountered during surveillance, ENG, and other urban oriented missions. However, despite the low level of traffic encountered, a non-negligible collision risk is inherent in this operation. The factors which impact that risk are twofold. First, due to the nature of these operations, they must be performed low to the ground, in many cases within 50 feet, and in the case of aerial applications, within ground effect. The proximity to the ground forces the attention of the pilot to the forward quadrants and at a distance consistent with obstacle avoidance. As such, little time can be spent scanning other quadrants and altitudes for conflicting air traffic. Secondly, rural operations can have the effect of eroding a pilots normal attention to other air traffic since it is so infrequently encountered. Thus when a conflict does arise it appears to develop suddenly, leaving the pilot little room or time to maneuver.

While these operations do entail frequent heading and altitude changes, the prospect that a helicopter TCAS might not be able to accurately predict the position of intruding aircraft was not a major source of concern to the pilots. For these pilots, an audible warning signal, perhaps tied to a visual quadrant display to show relative position of the intruder would provide a sufficient level of protection for their purposes. In fact, it was recommended that any TCAS design for very low level operations (below 100ft) would minimize the need for references inside the cockpit (i.e., visual displays) for the purpose of visually acquiring the target. The thought was expressed that spending too much time analyzing such displays could increase the possibility of a collision with the ground to an extent that that risk was greater than that posed by the intruding air traffic.

3.3.2.9.4 Powerline Pipeline Patrol

Another mission which helicopters are frequently tasked to perform is powerline/pipeline patrol. This mission may be performed in either rural, urban or suburban areas, under consequently varied air traffic conditions. These operations are performed at a fairly low altitude and airspeed consistent with allowing the pilot or observer the time to visually focus on and check a stretch of pipeline or power cable. This mission does entail numerous heading changes, although those heading changes are usually small, and often follow a several minutes long stretch of straight flight. As such, the missions should not seriously degrade the TCAS position prediction capability.

As with herding and aerial application missions, the pilots visual focus is outside the cockpit, downward in the forward quadrants, making him susceptible to the unexpected intruder. For this encounter, an alert system similar to that described for the aerial application, herding, and forestry aircraft may be sufficient. In areas of higher traffic density, such an alert only indication may be self defeating if the pilot perceives that the number of false alarms are a needless distraction. Because the position prediction capability is not severely degraded by this mission, a smarter TCAS able to discriminate between nearby and conflicting traffic may be the best option.

3.3.2.10 Weather Conditions

The survey group was questioned to determine the type of flight rules under which they were operating, and the prevailing weather conditions at the time of their most recent NMAC. Of 59 pilots who responded to the question, 44 or 74.6% of the respondents indicated that the conditions were VMC (visual meteorological conditions) and they were operating under Visual Flight Rules. Twelve pilots, or 20.3% of the respondents, reported they were flying in accordance with VFR, however the weather conditions were "marginal" VMC, indicating either a reduced ceiling or visibility or both. The most common restriction to visibility was reported to be either smog or haze. Two pilots reported that the NMAC occurred while operating under special VFR with a particular ATC controlling agency, with weather conditions IMC (instrument meteorological conditions) or marginal VMC. The remaining pilot reported that the NMAC occurred under IFR with visual meteorological conditions prevailing.

In general, there are no particular surprises to be found in these data. Helicopters operate primarily under VFR during VMC, so the high number of incidents reported under these conditions could be anticipated. Moreover, air traffic in general increases during periods of VMC, so the potential for NMACs increases as the number of aircraft increases. Finally, VMC promotes greater attention outside the cockpit, increasing the likelihood that conflicting aircraft will be detected. This implies, also, that during IMC, an encounter may not be detected, although it may exist, due to decreased visibility and the pilots attention to matters inside the cockpit.

3.3.3 Comparability of General Aviation Fixed-Wing and Rotary Wing NMAC Environment

The analysis of the rotary wing NMAC experience and operating environment points to several parallels with the fixed-wing environment. These parallels may be significant inasmuch as they give weight to the argument that while the helicopter exhibits a unique and rather large operating envelope, the NMAC experience of the helicopter operators/pilot may not differ radically from that of their general aviation (fixed-wing) counterparts. If this is true, it may be that the development of a TCAS suitable for the collision avoidance requirements of helicopters will be adaptable, to great extent, to fixed-wing aircraft, or vice versa. Such a circumstance would necessarily impact pricing of the TCAS units since the addition of the general aviation airplane market would increase the potential market for the TCAS by a factor of nearly 40.

It is true that the helicopter has unique flight characteristics which might tend to inhibit the effectiveness of TCAS. Those particular characteristics are the helicopter's ability to perform small radius turns and steep climbs and descent. In those situations where those capabilities are employed, such as in the police orbit mission (see description in Section 3.3.2.9) a TCAS with position prediction capabilities, which account for rapid heading and/or altitude changes of helicopters, may provide the only technical solution to the collision avoidance problem for helicopters. However, these particular missions do not represent the norm. While the helicopter does possess a unique operating envelope, during most phases of flight, the helicopter profile is indistinguishable from that of a general aviation airplane. Their are several reasons for this: First is that in those instances where the helicopter is involved in passenger service, whether corporate, commuter, EMS, charter or in any other form, passenger comfort is an important consideration for the pilot, and that comfort is degraded by such abrupt maneuvers as the helicopter is capable. Another factor is that pilot performance is enhanced by employing standard rate turns, and moderate climb and descent rates since he is less likely to become disoriented. This is particularly true during night operations or in periods of reduced or marginal visibility. Thus a pilot will normally climb and descend at rates between 500 and 1000 feet per minute, and turn at a rate of 3 degrees per second, and seldom exceeding 6 degrees per second (indicative of a maximum of 30° of bank angle). These parameters also describe standard maneuvering rates for light fixed-wing aircraft.

Rapid heading and altitude changes are exacerbated, for the purpose of position prediction and air traffic conflict resolution, when coupled with high maneuvering airspeeds. It is widely recognized that helicopters represent the low airspeed users of the NAS, and are largely slower than their fixed-wing general aviation counterparts. For example, the Cessna 150, which is largely representative the low/slow end of the fixed-wing market, has maximum allowable airspeed of 141 knots, a maneuvering speed 97 knots and a landing speed of 42 knots. This airspeed operating range corresponds to that of both piston and single engine turbine rotorcraft, and indicates that if a compatibility problem exists, it is that airplanes operate at higher airspeeds than helicopters. Thus it may be that a helicopter operating at low airspeeds with increased maneuverability may present the same position prediction problem for TCAS that the reduced maneuverability, higher airspeed of airplanes present.

3.4 TCAS COST/CAPABILITY TRADEOFFS

It has already been established through an analysis of the TCAS questionnaires and the discussions with the operator groups that mid-air collisions do pose a significant hazard to the pilot's operations. It remains therefore, to determine what are the specific collision avoidance informational requirements of the pilots, how that information is best displayed, and finally how much the operators might be willing to pay for such a system. In the following sections these specific aspects-desired capabilities, minimum information requirements, TCAS display requirements and pilots' price thresholds are discussed in detail.

3.4.1 <u>Desired Capabilities</u>

The survey group was asked to select from a list of five possible choices, the TCAS capability which best suited his needs for collision avoidance information. The five possible choices were A) Proximity Warning, B) Proximity Warning and Critical Quadrant Indication, C) Conflict Alert, Critical Quadrant Indication, and Relative Altitude Information, D) Items in "C" and suggested conflict resolution, and E) Auto pilot coupling of TCAS conflict resolutions, with a pilot override feature. Items A-D, it was felt, represented the probable maximum range of capabilities currently envisioned for helicopter use. The fifth (E), while not a feasible near term capability was introduced so as not to bias the response too heavily in favor of current technology.

The aggregate results for all operator groups are shown in Figure 3.17. As can be seen, there is an obvious skewing of the responses in favor of the least complicated advisory capabilities, with choices A and B representing over 48% of all choices. Choice C (proximity warning, critical quadrant, and relative altitude indication) was the most frequently selected capability, garnering over 42% of all choices. The remaining choices, D and E each received less than 5% of all selections.

If these findings can be shown to be representative of the entire helicopter pilot population, they should impact any future design considerations for helicopter TCAS. These data provide a rationale for eliminating from consideration those helicopter TCAS designs which include conflict resolution, (as well as all the software algorithms those capabilities infer), since the pilots do not display any great enthusiasm for those capabilities. Furthermore, 12% of the pilots cited a preference for the minimum TCAS capability of proximity warning, which is a capability which could be easily implemented using even older technology, and requiring no additional equipment purchases on the part of operators. Since a large number of pilots cited both critical quadrant indication and relative altitude information, both of the capabilities should probably be considered for implementation in order to provide operators with the widest possible range of <u>marketable</u> TCAS alternatives. Again, it should be noted that for the group selecting critical quadrant indication, an encoding altimeter is not required, again reducing the negative impact of low MODE-C equipage on TCAS utility. Since the most frequently cited desired capability (critical quadrant and relative altitude information) does require mode C equipage,

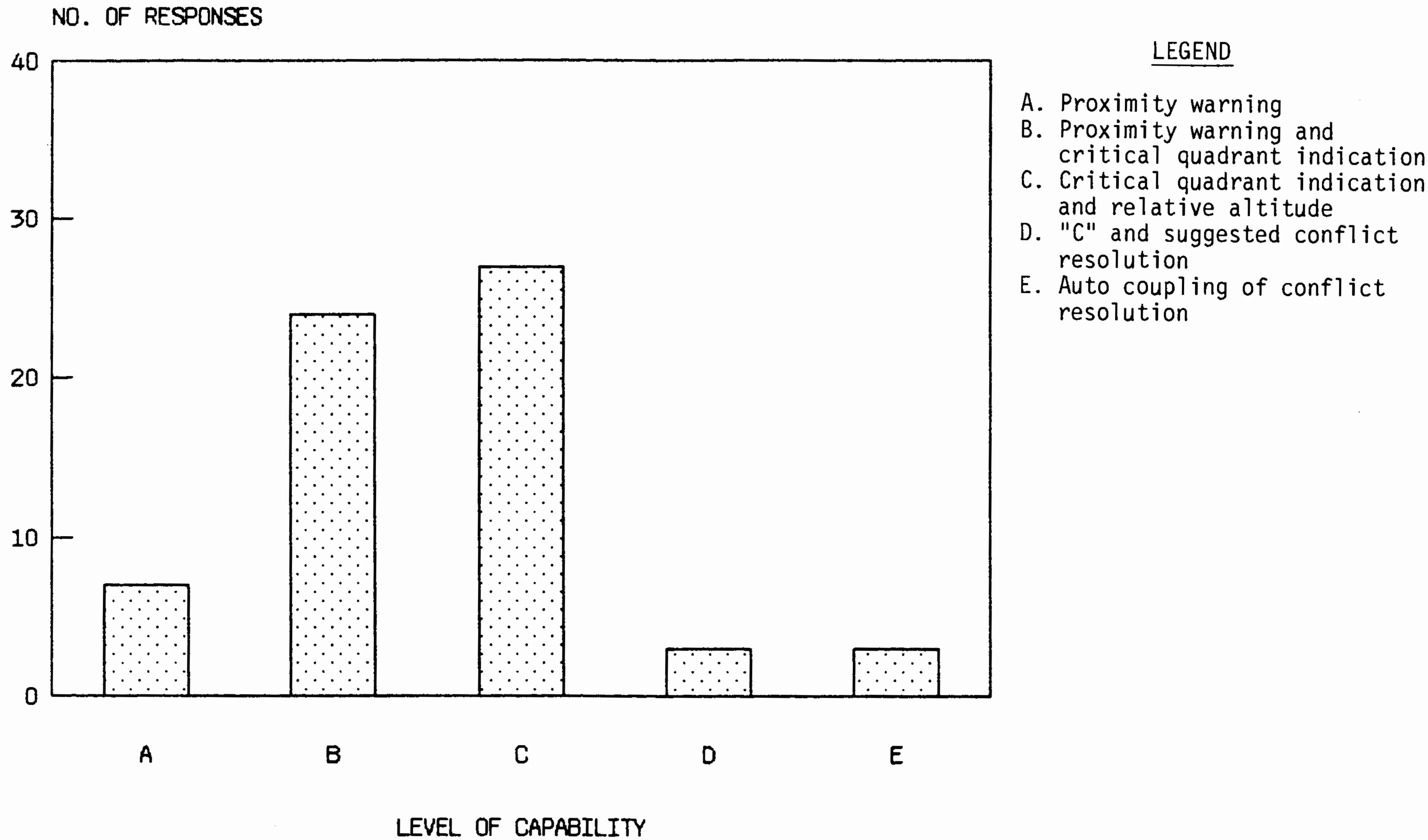


Figure 3.17 Desired TCAS Advisory Capabilities

and since the low incidence of that equipage among several of the operator groups has already been ascertained, it is encouraging that nearly 75% of those desiring the capability are currently equipped with the base equipment (MODE C) necessary to compliment the TCAS function.

The pilots' tendency to select the least sophisticated TCAS capability seems to be evident in each of the operator groups. Figure 3.18 shows the percentage of capability selections for each of the four primary groups. If these percentages are applied against the population as a whole, a rough order of magnitude estimate of the potential market size for each of the differing TCAS capabilities can be made, based on 1980 helicopter fleet size and mission distribution. Table 3.10 provides an estimate, of the potential market size, in terms of the total number of helicopters that could be equipped with TCAS of the varying levels of capability. Of significance is that fact that only 10% of the sample desire any sort of resolution advisory at all, and of that 10%, 70% (based on only 3 responses by commercial pilots) elected a decidedly non-feasible capability. No particular mission profiles or avionics purchase history, peculiar to the commercial operator has emerged which might provide a justification for the inordinate number of "E" responses obtained from those pilots. One possible unsubstantiated theory is that these pilots, who should be the most cost conscious of all the groups interviewed, and who evidenced the lowest NMAC encounter frequency, must envision a significant increase in the collision avoidance capability before they could justify the cost. This matter shall be further investigated in Section 3.4.4.

Table 3.10 Potential TCAS Market Size

		(# helicopters equipped) #	% of total market
A)	Proximity Warning only	1072	11.5
B)	Proximity Warning & Critical Quadrant Indication	3109	43.1
C)	Critical Quadrant and Relative Altitude Indication	3357	36.1
D)	"C" and Conflict Resolution Advisory	278	3.1
E)	"D" Above and Auto Pilot Coupling of Resolution Advisory	585	6.2

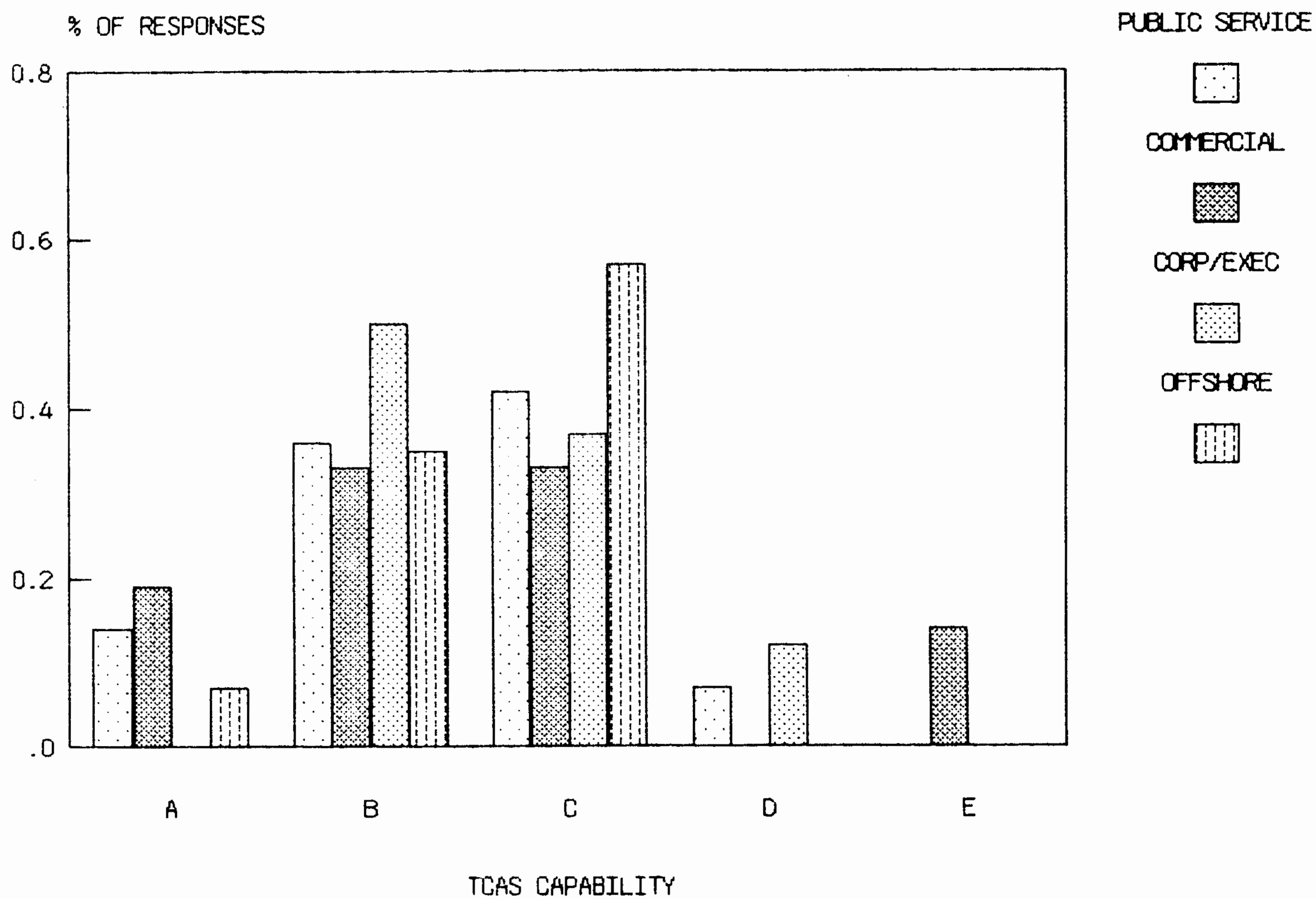


Figure 3.18 Percentage of TCAS Capability Selections by Operator/Pilot Type

3.4.2 TCAS Information Requirements

In conjunction with the question regarding the pilots' desired TCAS capabilities, the pilots were asked to select from a list of 9 (nine) items, those specific items of information which they would consider purchasing. To a certain extent, this question provides a calibration of the responses to the question of TCAS capabilities, since the items of information selected should represent functional requirements allocatable to the quasi-operational requirement stated as a response to question number 15. Beyond the functionality cross-check that the question provides, it also provides an indication of the level of sophistication and complexity of the TCAS design which will satisfy the anti-collision requirements of the users.

Figure 3.19 illustrates the distribution of pilot responses for the various selections. As with the responses to question #15 (TCAS capabilities), the responses A-I are arrayed from left to right along the X-axis in approximate order of the complexity of the information's derivation . As can be seen, the two most basic items of information, direction and distance to traffic garnered the most selections. However, this should not imply a bias against complexity, but only a recognition on the part of the pilot that these "basic" information items constitute the minimum data needed for them to perform the "see and avoid" function. Additionally, although items (C), (D), and (E), (representing 3 types of altitude information), received successively fewer selections than both (A) and (B), combined those items were selected by 61% of the respondents, indicating a desire for altitude information, the least complicated the better.

These three items of information - direction, distance, and altitude - represented the single most commonly cited functional configuration for the TCAS, with over 61% of the respondents desiring no more information than those items, Additionally of that 61%, over 34% did not desire any kind of altitude information. As with the responses regarding TCAS capabilities (see section 3.4.1) the pilots also displayed a tendency to select information items which could be readily assimilated so that they could quickly acquire, track and avoid conflicting air traffic. This predisposition is consistent with pilots operating in a rapidly changing air traffic environment, and with missions requiring a great deal of attention outside the cockpit. However, it should be noted that many of the pilots selected additional information, which, rather than just pointing to traffic, gives an indication of the level of hazard that the traffic poses. These items of information specifically express closure rate (F), convergence-divergence of traffic (G), time to closest approach (H), and end of conflict (I). Two groups in particular selected one or more of these items of information. The first group is the commercial operators. Pilots in this group, although they represent only 28% of all pilots who responded to the question still were responsible for over 40% of all the responses in this category. This response is consistent with

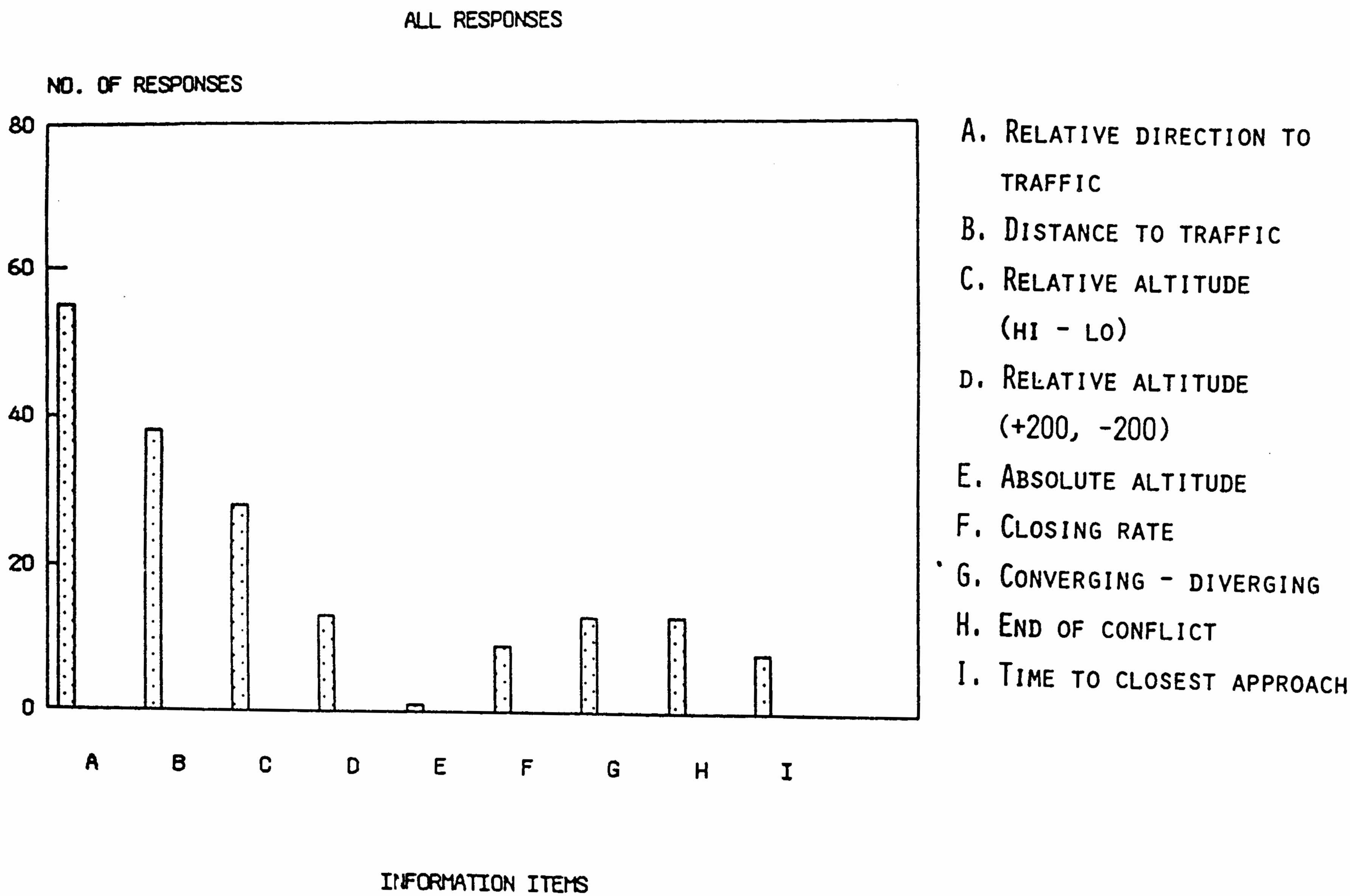


Figure 3.19 Distribution of Pilot Selections of Minimum TCAS Information Requirements

the commercial pilots previous selection of the more sophisticated TCAS capability, and can probably be explained along the same economic grounds.

The other group which selected the more sophisticated items of information was the offshore operators. These pilots split nearly equally their selections of both convergence-divergence and time to closest approach information. Again, the nature of their missions, which entails long enroute legs, may afford these pilots a better opportunity to assimilate and act upon these additional items of information.

Generally, it can be said that the items of information desired are consistent with the previously cited minimum TCAS capabilities, with the exception that a significant minority desired information not readily allocatable to one of the several capability options presented. Two of these information items in particular, convergence/divergence and time to closest approach, received a substantial (22% each) number of selections. This selection indicates that the pilots would like additional information which would assist them in prioritizing their actions according to the level of hazard. A corollary proposition is that pilots would rather not be alerted to traffic within their protected radius unless it poses a direct collision threat to his operation. This implies that some prediction capability should reside in the TCAS in addition to the detection only capability suggested by the results to question #15.

If the results from the sample of commercial and offshore pilots are indicative of those groups as a whole, estimates for the number of TCAS's enhanced with the limited collision prediction capabilities may be made. Helicopters engaged in offshore and other commercial operations account for 65% of the 8500 helicopters currently in use. Previously it had been determined that a potential exists for those operators to purchase a total of 1853 TCAS "B" (proximity warning and critical quadrant indication) and 2158 TCAS "C" (proximity warning, critical quadrant and relative altitude indication) systems, based on the following schedules:

Operator Group	TCAS "B"	TCAS "C"
Offshore	484	789
Commercial	1369	1369
TOTAL	1853	2158

It can be argued that those pilots who selected the TCAS "C" would be more likely to desire the enhanced TCAS with collision prediction capability. As such, TCAS enhancement should be applied to the TCAS "B" and TCAS "C" in accordance with some estimated probability. For the purpose of this discussion, a 75-25 split will be applied, although that allocation may vary considerably in reality. Applying this split to the previously allocated TCAS "B" and TCAS "C" quantities, and to the percentage of the pilots from each group desiring the enhanced capability, the following quantities of enhanced TCAS, shown in Table 3.11, are derived.

Table 3.11 Estimated Enhanced TCAS Market Size

Operator Group	% Desiring Enhancement	TCAS Variant	Base Qty	Potential Market
Offshore	12.5%	TCAS "B"	484	61
	37.5%	TCAS "C"	789	296
Commercial	9.38%	TCAS "B"	1369	128
	28.12%	TCAS "C"	1369	384
	TOTAL	TCAS "B"		189
		TCAS "C"		680

The quantities shown do not distinguish between various types of information which may comprise the TCAS collision prediction enhancement. It is sufficient to state the survey indicates that a significant market (approximately 11% of all civil helicopters) desires more than intruder detection, but something less than conflict resolution.

3.4.3 Pilot Display Preferences

One aim of the survey was to determine the most effective means of displaying TCAS advisory data. Question #17 addressed this goal by requesting that the pilots rank each of six possible display options according to the effectiveness of their data presentation. Those options are as follows:

A - Warning lights

B - Audio Warning Tones

C - Digital Displays

D - Video Displays

E - Synthetic Voice Warnings

F - Combination of A - E (pilot specified)

These display formats were selected as being representative of the range of options which might be employed in a helicopter TCAS system.

In this case, again, the pilots evidenced a strong preference for a simple display, the highest ranked solo display format being audio warning tones. Table 3.12 lists the mean ranking of each of the display options.

Table 3.12 Ranking of Pilot Display Preferences

	Display Format	Mean Ranking*
1.	Combination	2.14
2.	Audio Tones	2.35
3.	Warning Lights	3.30
4.	Video Display	3.77
5.	Synthetic Voice Warning	3.93
6.	Digital Display	4.0

*Scale - 1 strong preference, 6 strong dislike

Pilot preferences for an uncomplicated display is in evidence even in those instances in which they ranked a combination display as the most effective means of presenting anti-collision information. The pilots were asked to specify which of the individual formats comprised their ranked "combination" option. Table 3.13 shows the frequency of citations for each of the several individual formats which were specified when the combination format was ranked as most effective.

Again the most frequently cited formats were audio tones and warning lights, in that order of preference. The two display formats, in conjunction, were selected by over 50% of the respondents who rated the combination display as best. In discussions with the subject pilots, they stressed the need to minimize the necessity of diverting attention inside the cockpit to the monitor anti-collision data. Rather, they desired a warning system which would call attention to a visual display to allow them to quickly determine intruder position, and finally to visually acquire the target. Their preference for audio/visual display formats is consistent with this requirement.

With this in mind, it is surprising that the synthetic voice format was rated so poorly. That format was ranked as the least effective or second least effective format by 1/2 of the 42 respondents who rated it,

Table 3.13 Breakdown of "Combination" Display Format Preferences

Combination Display Format		Number of Responses
Warning Audio Tones, Warning Lights	(A,B)	6
Audio Warning Tones, Digital Display	(A,E)	3
Audio Warning Tones, Warning Lights, Synthetic Voice Warning	(A,B,D)	2
Warning Lights, Video Display, Synthetic Voice Warning	(B,C,D)	2
Warning Lights, Digital Display	(B,E)	2
Synthetic Voice, Digital Display	(D,E)	2
Audio Warning Tones, Video Display	(A,C)	1
Audio Warning Tones, Synthetic Voice	(A,D)	1
Audio Warning Tones, Warning Lights, Video Display	(A,B,C)	1
Audio Warning Tones, Warning Lights, Digital Display	(A,B,E)	1
Warning Lights, Synthetic Voice Warnings	(B,D)	1
Audio Warning Tones, Warning Lights, Synthetic Voice, Digital Display	(A,B,D,E)	1
Audio Warning Tones, Warning Lights, Video Display Synethetic Voice Warning	(A,B,C,D)	1

and best by the fewest (3) respondents. It would seem that such a system could provide the capability to alert and provide position information without ever calling the pilots attention inside the cockpit. That format does somewhat better when integrated with a combination display format, ranking 4th of 5 possible selections. This particular anomaly should be further investigated prior to selection of any display format for helicopter TCAS, since it appears to hold the potential for the sort of unobtrusive data dissemination format desired by the pilots.

One possible explanation for the anomaly and for the generally mediocre to low ratings given to video and digital displays is that pilots are unfamiliar with, and in many cases distrustful of these display formats. It is probably not a coincidence that the formats rated best, a combination of audio warning tones and warning lights, are the same as that used currently on malfunction annunciator panels. Moreover in the experience of most of the pilots, the system which most closely resembles the functions of TCAS is the Proximity Warning Device (PWD), used at military flight training centers. That equipment also employs an audio alert and lighted panels to indicate the direction to the traffic. Thus, their inexperience with digital, video, and synthetic voice formats, coupled with their familiarity with the PWD may have forced a bias in their selections. It is probable that in this instance, a human factors analysis of display formats, rather than a polling of pilot perceptions would produce a more effective display format.

3.4.4 TCAS Price Thresholds

Price thresholds are a matter of some interest in this study, since they are an indicator of the size of the potential market for TCAS at a given cost. As the price of the TCAS increases, whether that increase is a result of adding additional capabilities, more expensive displays, or because of a limited production capacity, the size of the TCAS market will dwindle. Likewise, if the price should be lowered, the market will expand. Therefore, in order to insure the wide acceptance and usage of TCAS, it is extremely important that the TCAS afford the users with a sufficient anti-collision capability and within an acceptable price range so as to stimulate its acceptance. In the following paragraphs the aspect of pricing thresholds and capability/display mixes are discussed.

Up until this point, the terms "operator" and "pilot" have been used interchangeably. That usage is acceptable when the purpose was to describe the NMAC environment and preferences for TCAS capabilities, since an operator who is a pilot can largely be expected to have a similar NMAC experience as other pilots operating in the same geographic regions, and for purposes of his own self interest (and protection) could be expected to specify TCAS requirements which would serve the purpose of avoiding NMACs. However, when considering pricing for the various TCAS capabilities and configurations, operators and pilots can be expected to have divergent opinions. This is because a pilot would naturally be expected to place a very high value on a device which can save his life, such as TCAS. An operator, on the other hand, is acutely aware of expenses involved in running his service, and consequently would be less willing to spend money on a device whose safety impact has not been demonstrated.

Throughout the remainder of this discussion, the use of the term "operator" implies only pilots and operators who are pilots. As will be seen by the conclusion of this discussion, this distinction may be totally unnecessary, since the survey sample indicated an exceptionally low price threshold for the TCAS.

At the time that the questionnaire was developed, a firm decision regarding TCAS capabilities and displays had not been made. It was decided, therefore, that rather than presenting alternative TCAS designs and asking pilots to tell us how much they would be willing to spend on them, we would allow them to design a system suitable to their needs and then price that system. Questions 15, 16, and 17, already discussed in Sections 3.4.1, 3.4.2, and 3.4.3 of this report, allowed the pilot to specify his minimum collision avoidance capability, information requirements and display preferences, The pilots were then asked, in question #36 to indicate how much they would be willing to spend on a TCAS systems such as he had described. Figure 3.20 shows percentage of responses, for each operator group, for the price ranges indicated. It is apparent, even with the most cursory examination of these data, that the pilots are not presently disposed to spending much money for the TCAS. Nearly 50% of the respondents who indicated a price threshold selected the lowest, $1000 to $2500, and fully 86% of the pilots indicated a threshold of less than $5000. If these percentages are projected across the entire civil helicopter population as a whole, the results are equally as dramatic. Figure 3.21 shows the results of that projection. In this case the percentage willing to spend no more than $5,000 remains constant at about 86%, however the number willing to spend no more than $2500 increases to 54% of the total. The explanation for this increase lies in the fact that the commercial pilots, who represent the largest segment of the civil helicopter population, indicated an unwillingness to spend more than $2500 fully 60% of the time.

It would be a mistake to infer from these data that operators would not be willing to spend more than they indicated. It is quite likely that their reluctance to select a higher price threshold is because they are afraid some marketeer might use those selections as a basis to increase the price. Thus, the low price threshold alone should not force a conclusion that pilots are unenthusiastic about TCAS. Question #35 provides a barometer for their enthusiasm. Pilots were queried as to whether they would purchase immediately, purchase as soon as economically practical, consider a purchase or not purchase a TCAS such as they had described in their responses to questions #15, 16, and 17. The

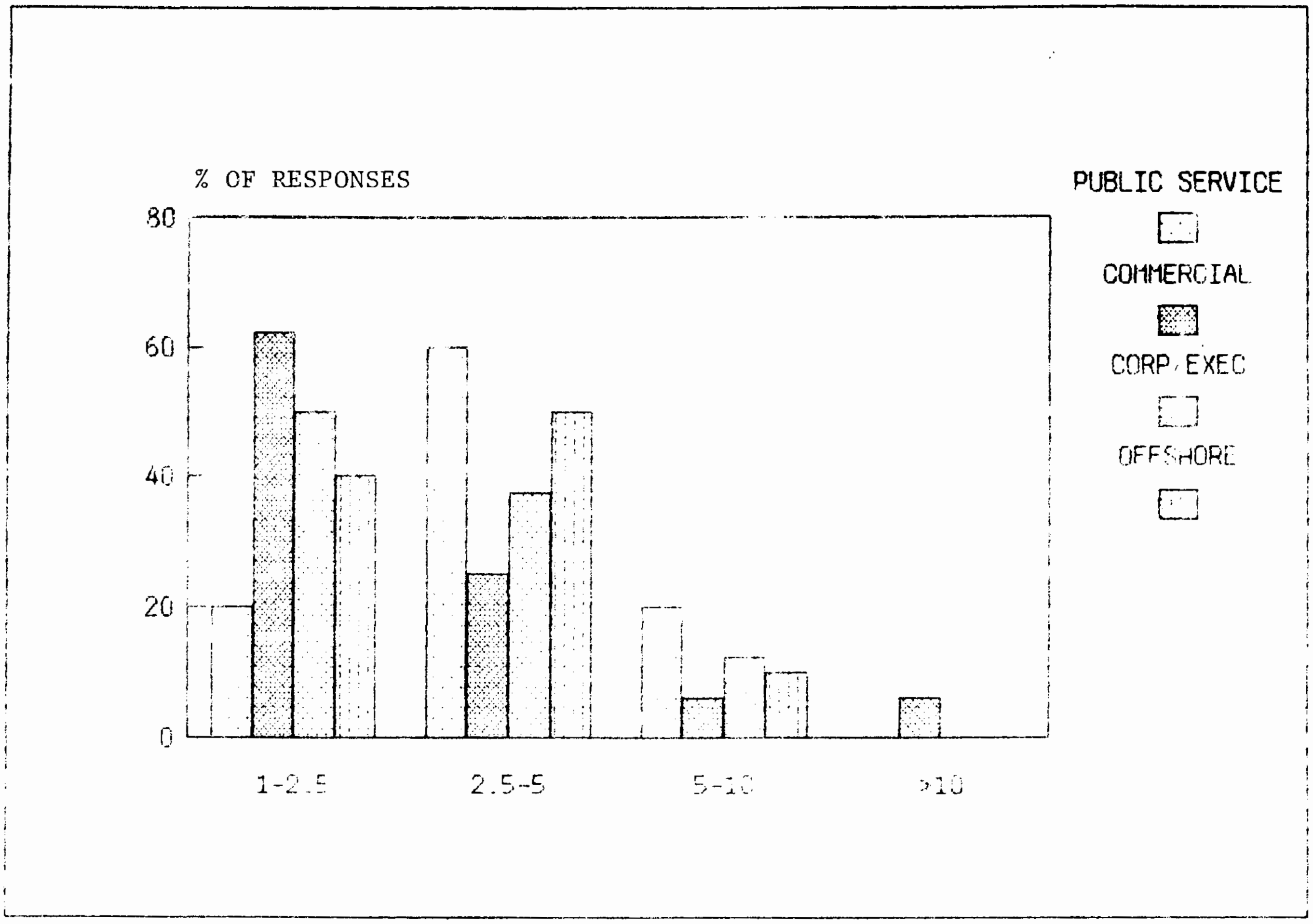


Figure 3.20 TCAS User Price Preferences

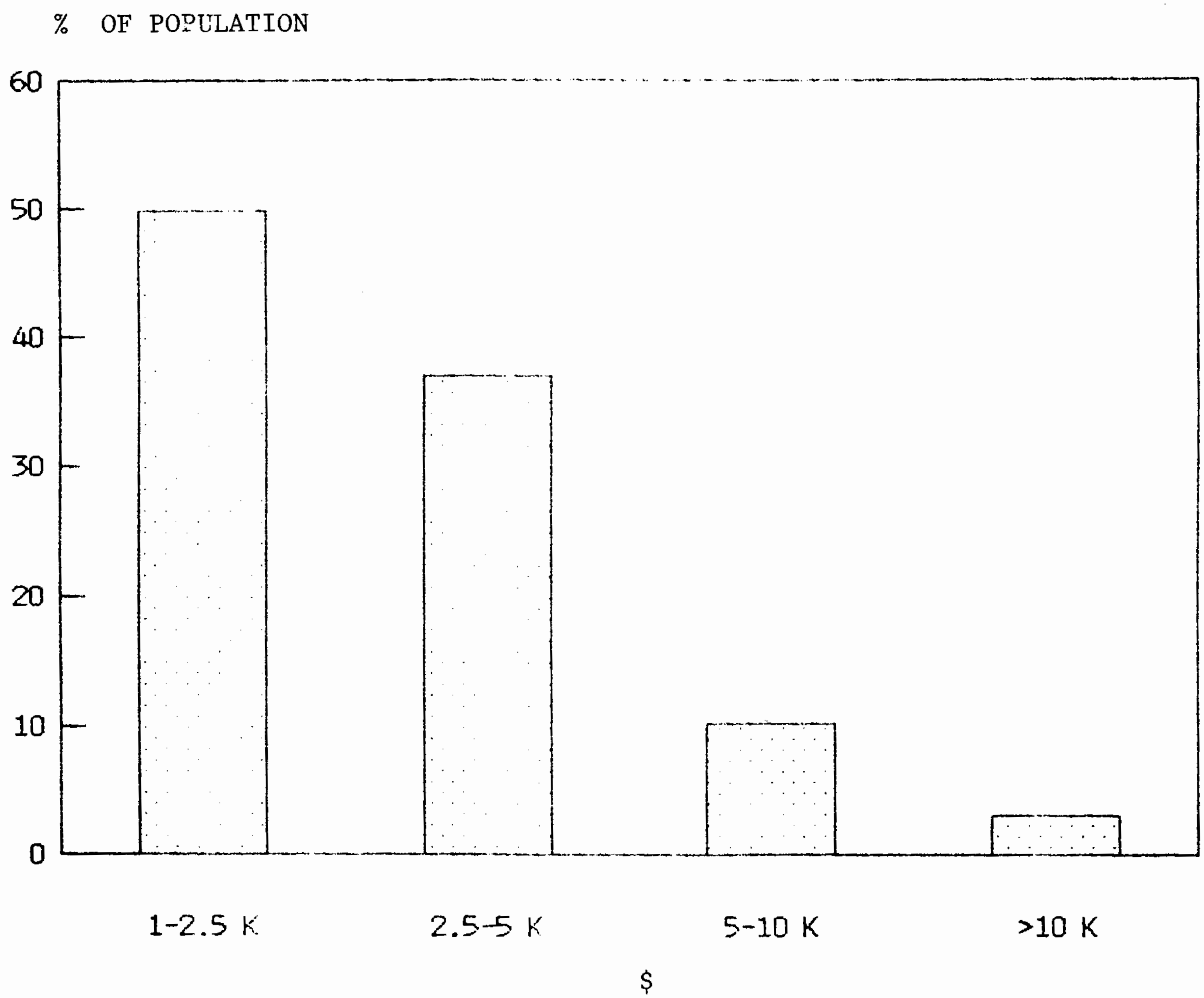


Figure 3.21 Projected Distribution of TCAS Price Thresholds

distribution of responses are shown in Figure 3.22. This figure shows the percentage of each group's responses attributed to each purchase option. It is apparent that the vast majority of the pilots still need convincing, with well over 40% of them saying they would only consider a purchase. A significant minority of pilots indicates a desire to purchase a TCAS system either immediately or as soon as economically practical, with the public service pilots showing the greatest enthusiasm for a system. On the negative side, over 10% of the respondents stated that they would not purchase any system.

Figure 3.23 projects these percentages across the helicopter population, causing a somewhat less optimistic view of the pilots enthusiasm, again tempered by the more negative commercial pilots response. For the whole population, the data suggests that half the pilots would be neutral to a TCAS purchase, over 27% would purchase at some point in time and nearly 18% would not purchase in any event.

Up to now, two facts are clear regarding pilots' price threshold and desire to purchase TCAS. They are that pilots are, in general, not sure of the utility of TCAS, but are willing to be convinced, and in any event they are unwilling to spend a great deal of money for a TCAS. These conclusions are based on aggregate responses, independent of the TCAS systems they described in questions 15, 16, 17. To obtain a clearer picture of their desire for a TCAS requires that pilot price threshold and propensity to purchase be compared against the pilots' desired TCAS configuration. Figure 3.24 shows the results of correlating the pilots desired capabilities vs the price they indicated they would be willing to pay for the capability. (As a word of explanation the following list provides a description of the terms TCAS "A", etc.:)

- TCAS "A" - Proximity warning only
- TCAS "B" - Proximity warning and critical quadrant
- TCAS "C" - Critical indication quadrant and relative altitude indication
- TCAS "D" - TCAS "C" with resolution advisory
- TCAS "E" - TCAS "D" with autopilot integration

The prices shown are projections based upon the mean price response for each operator group, normalized to the entire civil helicopter population. The average threshold price is simply an interpolation of the normalized mean price response for a particular TCAS option. For example a mean price response of 1.41 is computed by first multiplying the integer of the mean price response (1) by the maximum range value represented by that integer (in this case, $2500). To this is added the product of the decimal remainder of the mean price response (.41) and the delta between the maximum lower bound ($2500) and the minimum upper

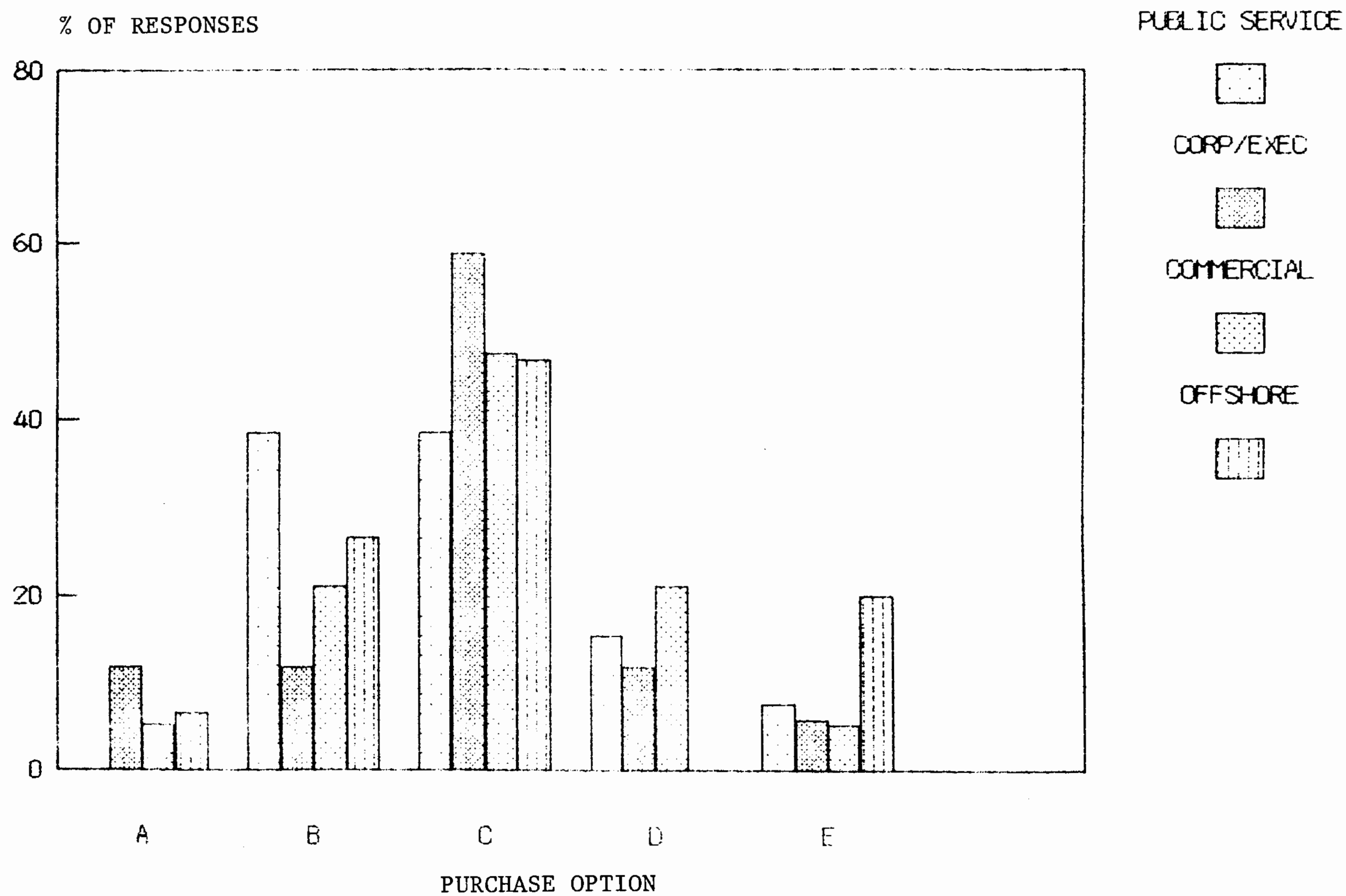


Figure 3.22 Pilot's Purchase Enthusiasm, By Operator Group

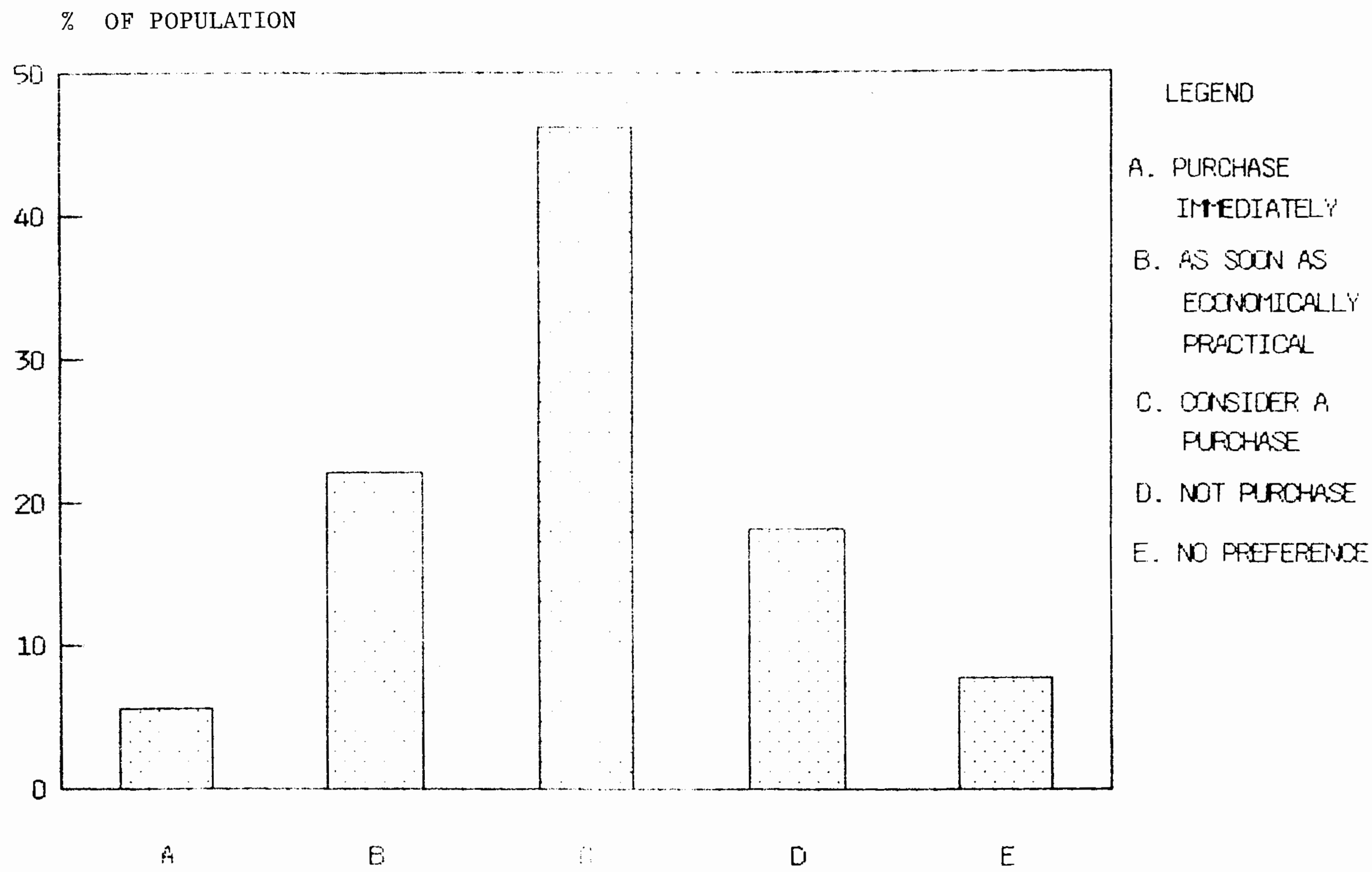


Figure 3.23 Projected TCAS Purchase Potential (All Pilots)

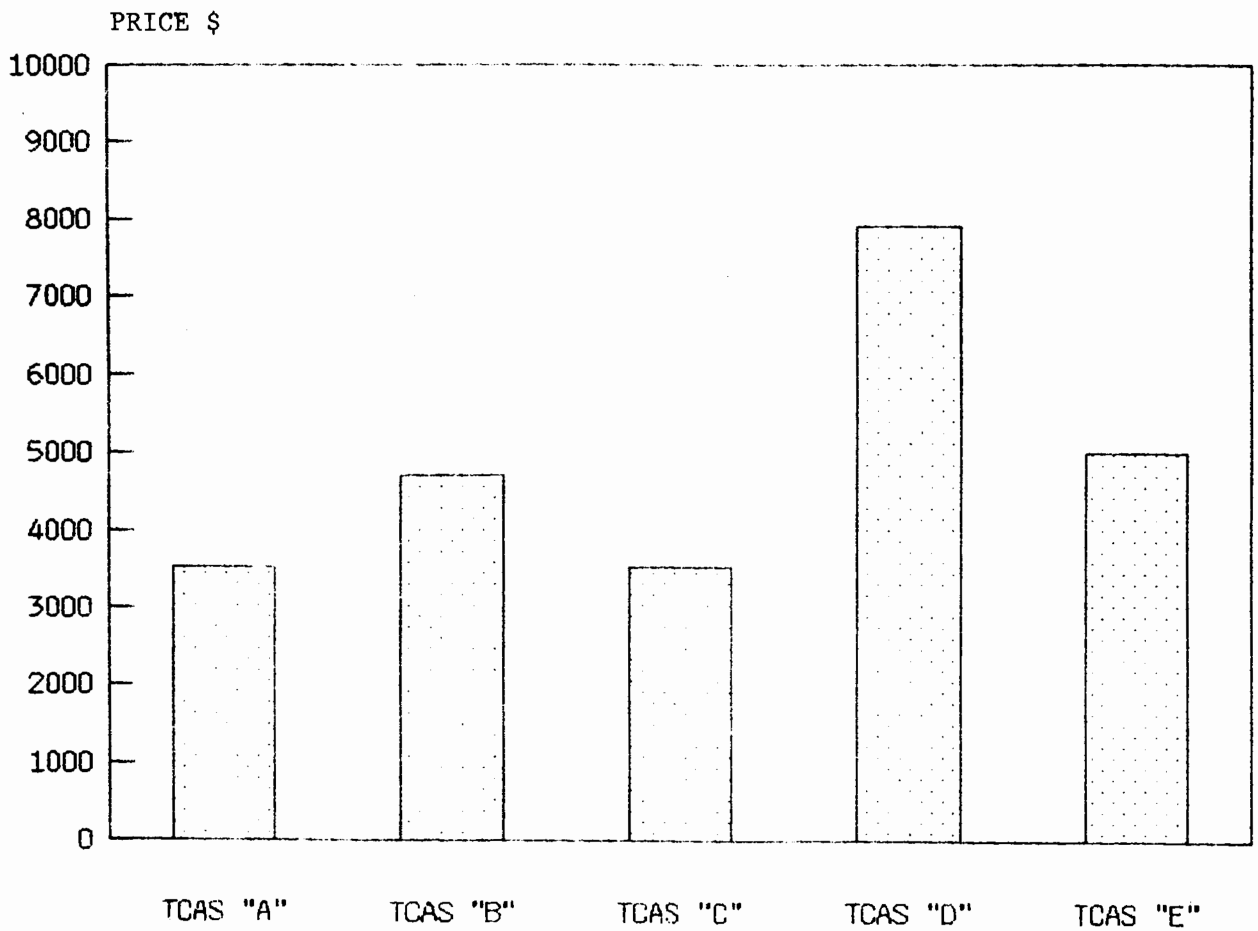


Figure 3.24 Estimated Price Threshold Per TCAS Capability

bound represented by the next highest integer whole number (2). Since a response of 2 represents the range of $5000-$10,000, the price threshold value of 1.41 is computed as:

$$PT = 1. \times (\$2500) + .41\ (5000-2500)$$

or

$$PT = 1.41$$

One might have thought that pilots would be disposed to paying more for additional capability. To a certain extent, this supposition is born out by the data, although given the small price range (less than $4400) within which all the averages lie, it is difficult to lend too much credence to the conclusion. It is interesting to note that the single response which indicates a threshold greater than $10,000 was for a TCAS "B" capability. That response came from a commercial pilot engaged in a scheduled air carrier operation. His response may well be indicative of that particular, small category of commercial operators, but should not be construed to represent the whole group. If that response is removed from the data, the price threshold for TCAS "B" drops to approximately $2450, closer in line to both the TCAS "A" and TCAS "C". Furthermore, since the average prices for TCAS "D" and TCAS "E" are projected from only 3 and 1 responses respectively, it would be dangerous to place too much confidence in these particular data. The only conclusion that can be safely drawn from these data is that TCAS capability has only a nominal impact on the pilots price preference, and that that preference is consistently low across the range of capabilities.

Finally, it remains to be determined whether pilots who expressed a preference for a given TCAS capability, also demonstrated a pattern of enthusiasm for the purchase of the capability. To test this hypothesis, the data from questions 15 and 35 were arranged in a matrix comparing pilot group specific TCAS capability and enthusiasm responses. An average enthusiasm response was then computed for each TCAS capability. The results are shown in Table 3.14.

Table 3.14 Average Purchase Enthusiasm Rating

Capability	Raw Rating	Weighted* Rating
TCAS "A"	2.66	2.78
TCAS "B"	2.75	2.93
TCAS "C"	2.5	2.59
TCAS "D"	2.25	2.58
TCAS "E"	2.5	2.5

*Projected across U.S. helicopter pilot population.

The rating scale used is comprised of a range of 4 possible responses. They are:

1 - purchase immediately

2 - purchase as soon as economically practical

3 - consider a purchase

4 - not purchase

The range of responses shown, ranging from 2.5 to 2.93, indicates that the pilots are not overwhelmed by the prospect of having a TCAS with the minimum capability (that he would purchase) on the market. Encouragingly, the results are not negative. In fact, if an average response of 3 is considered completely neutral (which it should be), the results show that the majority of pilots are predisposed towards a TCAS purchase.

Given the findings described in this section, and assuming that the results can be projected across the entire civil helicopter population, it is possible to estimate quantities of TCAS of varying capabilities which might be purchased by operators of the fleet. Again, it can not be emphasized enough that inferring TCAS purchases for the whole population from such a limited sample could well produce misleading results. And because of the multiplicative impact of combining confidences for each of the singular conclusions/assumptions which comprise the calculation of market size, the overall confidence rating for that number must necessarily be small. However this analysis is incomplete without that final estimate.

The total quantity shown Table 3.15 for each TCAS type, was derived as follows. Deducted from the base market for each TCAS capability (derived in section 3.4.1) was the average percentage of "will not purchase" responses, resulting in an adjusted market base for each capability. From the enthusiasm rating a percentage "will purchase" coefficient was calculated. The calculation assumes that at an enthusiasm rating of "3", 50% of the operators will eventually purchase equipment and at "2", 100% of the operators will purchase (see the discussion on enthusiasm ratings from the previous page). The base purchase percentage is therefore calculated as follows:

Purchase % = 50 + 50 (3.- Enthusiasm rating)

Finally, the purchase % is halved since price threshold is in the level at which half the operators will purchase the TCAS.

Obviously, the results obtained from this methodology are only as valid as the basic assumptions used to calculate them, and there may be considerable disagreement with many of them. However, the purpose of the calculations are to provide rough order of magnitude estimates of the quantities for each TCAS type. By that measure, they are certainly acceptable estimates.

Table 3.15 Projected TCAS Market Size vs Price Threshold

Configuration	Base Market*	Adjusted Base***	Enthusiasm Rating	% will Purchase	Total Qty	Price Threshold Hold
TCAS "A"	1072	929	2.78	30.5	283	$3,525
TCAS "B"	3109	2695	2.93	26.8	833	$4,700**
TCAS "C"	3357	2910	2.59	30.5	1024	$3,525
TCAS "D"	278	241	2.58	35.5	99	$7,900
TCAS "E"	585	507	2.5	37.5	219	$5,000

(population = 8401 helicopters)

*From Table 3.10
** $4700 amount impacted by a single air carrier who indicated a willingness to spend in excess of $10,000 for the capability.
***Base market less that those who "will not purchase"

4.0 CONCLUSIONS

This section addresses the qualitative conclusions which have been derived from the survey results and discussed in detail throughout the previous section. The conclusions provided are organized in the order in which they were derived in Section 3.0 for ease of cross referencing the relevant quantitative data discussions.

4.1 GENERAL

- Helicopter Near Mid-Air Collisions involving both fixed-wing and other helicopters are far more frequent and present a significantly greater hazard than can be supported by voluntarily reported NASA data.

- Operating altitudes below 1000 feet and reduced ceiling/visibility operations will significantly reduce the utility of vertical only conflict resolutions.

- Helicopter pilots are, in general, not sure of the utility of TCAS, but are willing to be convinced. However, they are not willing or capable of spending a great deal of money for a TCAS.

4.2 CENSUS CONCLUSIONS

- The survey respondent population was of sufficient size to provide a rough order of magnitude description of the total U.S. helicopter pilot population.

- The distribution of the survey respondents by mission type was similar enough to the total U.S. distribution to allow extrapolation of survey results by mission categories and requirements.

- The survey respondents were geographically distributed and selected to include those areas which had both a high degree and a low degree of reported Near Mid-Air Collisions (NMACs).

- Current avionics equipage expenditures by each user category showed that the feasibility and capability of a TCAS purchase was consistent with past spending trends.

4.3 ROTORCRAFT TCAS REQUIREMENTS

- NMACs occurred with a frequency of 1.5/year for all operator categories. Extrapolated to an annual flying hour perspective this becomes 7.3 NMAC/1000 hours.

- The number of NMACs are apparently more geographically dependent than mission or operator category dependent. That is NMACs are higher where the density of helicopter basing is highest.

- Rotary Wing-Fixed Wing NMACs represent up to 77% of the reported encounters. However, the degree to which the Rotary Wing-Rotary Wing encounters has been reported appears to be understated.

- Nearly three-fourths of the helicopter NMACs occurred during straight and level flight. However, encounters during a left turn were 2.5 times more likely than during a right turn.

- Mean Airspeeds at the time of an NMAC encounter were mission dependent as follows:

  * Public Service - 66 Knots
  * Commercial - 88 Knots
  * Corporate - 103 Knots
  * Offshore - 117 Knots

- The helicopter's low airspeed allows a substantially smaller volume of protection than that necessary for air carriers. The maximum coverage radius for a high speed (132 Knot cruise airspeed) helicopter is approximately 4.8 nm.

- The mean NMAC encounter altitude for all helicopter pilots was approximately 750 feet AGL. However, encounter altitude was also somewhat mission dependent (617 feet for Public Service to 1508 feet for pilots on the offshore operator group.

- The NMAC environment of rotorcraft does not differ significantly from that of light G.A. aircraft (i.e., location - near airports; airspeeds - less than 140 knots; altitude - less than 1000 feet; and flight mode - straight and level). As such, a TCAS developed for helicopters may be applicable to fixed-wing as well, or vice versa.

- Over 75% of all survey respondents cited either the left or rear quadrant as the most critical encounter situation. The most frequently cited worst case collision scenario involved a fixed-wing aircraft descending towards the helicopter from the rear or critical quadrant.

4.4 COST VS CAPABILITIES CONCLUSIONS

- Helicopter respondents polled do not desire highly sophisticated or exotic TCAS capabilities. A simple proximity warning and critical quadrant indicator is preferred. Display preferences were for audio tones and warning lights.

- 86% of the respondent pilots indicated a TCAS price threshold of less than $5000.

REFERENCES

1. Adams, R.J.; Taylor, F.R., "Traffic Alert and Collision Avoidance System (TCAS) Data Collection and Analysis Plan", Systems Control Technology, Inc. October 1983.

2. Billman, B.R., "Survey of Characteristics of Near Mid-Air Collisions Involving Helicopters", DOT/FAA/CT-83/40, Federal Aviation Administration Technical Center, August 1983.

3. Adams, R.J., "Helicopter Operations Survey", Systems Control Technology, Inc., June 1982.

4. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, Volume I", Radio Technical Commission for Aeronautics, RTCA/DO-1985, September 1983.

5. "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, Volume II", Radio Technical Commission for Aeronautics, RTCA/DO-1985, September 1983.

APPENDIX A

SCT DEVELOPED TCAS REQUIREMENTS SURVEY QUESTIONNAIRE

Questionnaire No. ______

TCAS REQUIREMENTS SURVEY

The following questions are pertinent to the assessment of the operational needs and potential pilot usage of an airborne TCAS. the answers to these questions will be used in a comprehensive study being performed for the Federal Aviation Administration. This study includes analysis of safety hazards, development of pilot workload profiles and determining the "pilot usage" criteria for TCAS avionics.

The objective of the TCAS approach is to provide a range of collision avoidance equipment alternatives that can provide collision protection for the full spectrum of airspace users ranging from helicopters and general aviation aircraft to large transport aircraft. The TCAS is an aircraft mounted conflict warning system designed to provide the pilot of an aircraft with various levels of collision protection according to his operational needs. The least expensive option, TCAS I, intended for installation in small general aviation aircraft, will simply provide an alert to the pilot indicating that an intruding aircraft is in the near vicinity. No indication of the position (range, altitude, or bearing) of the intruding aircraft would necessarily be given. A more sophisticated TCAS I unit would be capable of not only providing an alert that an aircraft is nearby but would also indicate the relative position of the intruder by displaying a traffic advisory on an appropriate display in the cockpit. The top-of-the-line TCAS equipment, TCAS II, intended for installation in transport and high performance general aviation aircraft, would not only be capable of providing alerts and traffic advisories but would also compute resolution advisories to indicate which direction the TCAS aircraft should maneuver in order to avoid a collision. In order for resolution advisories to be generated, an intruder must report his Mode C altitude through his transponder.

One of the primary purposes of this questionnaire is to determine the level of sophistication (i.e., alert, advisory, or resolution) required by helicopter operators. A secondary, but equally important, objective is to determine those operations (missions, flight paths, etc.) which may have to be excluded from the utilization of TCAS due to difficulties in predicting heading or altitude changes.

Please note that there is no intention on the part of the FAA to mandate the installation of TCAS on any aircraft. Results from this questionnaire will be published in an aggregate manner to assess the functional needs and develop the TCAS equipment consistent with helicopter operator requirements.

1. During the last six (6) months, how often have you encountered conflicting air traffic at ranges of less than 1000 feet that required you to perform some evasive action to resolve the conflict (please check the appropriate group):

____ a. 0 ____ d. 3
____ b. 1 ____ e. 4
____ c. 2 ____ f. 5 or more

2. During your most recent "near miss encounter", your aircraft was in a:

____ climb
____ descent } Answer 1
____ level

____ left turn
____ right turn } Answer 1
____ straight flight

3. During your most recent "near miss encounter", the conflicting aircraft was in a:

____ climb
____ descent } Answer 1
____ level

____ left turn
____ right turn } Answer 1
____ straight flight

4. During your most recent "near miss encounter", your airspeed was:

____ less than 40 Kts
____ 40-60 Kts
____ 60-120 Kts
____ 120-150 Kts
____ more than 150 Kts

5. What was the closest approach distance between your aircraft and conflicting aircraft in your most recent encounter:

____ 1. less than 50 feet
____ 2. 50 - 100 feet
____ 3. 100 - 200 feet
____ 4. 300 - 400 feet
____ 5. 400 - 500 feet
____ 6. 500 - 1000 feet
____ 7. more than 1000 feet

6. During your most recent near miss encounter, were you operating: (NOTE: Marginal VMC = VIS of 1-3 miles or less than VFR cloud clearance)

____ 1. VFR, VMC
____ 2. VFR, marginal VMC
____ 3. S-VFR, marginal VMC/IMC
____ 4. IFR, VMC
____ 5. IFR, marginal VMC
____ 6. IFR, IMC

7. Were you receiving radar advisories during your most recent near miss encounter?

____ yes ____ no

8. At what altitude (AGL) were you operating at the time of your most recent air traffic conflict:

____ feet (AGL)

9. In your experience, does the primary helicopter you fly exhibit any radio reception or transmission "dead zones" (i.e., zones of intermittant or continuous inability to receive or transmit radio signals):

____ yes ____ no

10. If yes, are these zones most pronounced during:

____ a. climbs
____ b. descents
____ c. straight and level flight
____ d. turns toward the transmitting/receiving station
____ e. turns away from the transmitting/receiving station

11. List your onboard radio (VHF, VOR, DME, transponder, etc.) equipment which demonstrates the greatest susceptibility to "dead zones":

____
____
____

12. According to your experience, which of the four (4) described quadrants represents the primary or critical collision hazard?

____ 1. front
____ 2. right
____ 3. rear
____ 4. left

13. In your experience, how have you most often maneuvered to avoid collisions?

____ a. Vertically (climb/descents)
____ b. Horizontally (left/right turns)
____ c. Laterally (decel/acceleration)
____ d. Combination [specify - ( ), ( ), ( )]

14. Based on your experience, rank order the following factors according to their significance as causes of, or factors in aerial traffic conflicts and near misses. (1 is most significant, 7 is least significant):

____ a. Critical quadrant
____ b. Vertical environment
____ c. Type A/C
____ d. Type maneuver or operation (describe ________________________________)
____ e. ATC involvement
____ f. Phase of flight (specify ________________________________)
____ g. Terminal Proximity

15. Which collision alert capabilities would you desire in any TCAS system you would consider purchasing?

_____ a. Proximity warning

_____ b. Proximity warning and critical conflict quadrant indication

_____ c. Critical conflict quadrant indication and relative altitude indication

_____ d. Item "c." above and suggested conflict resolution

_____ e. Auto pilot coupling of conflict resolutions with pilot override

16. What specific minimum information would you desire from a collision avoidance system that you would consider purchasing? (check appropriate blank[s])

_____ a. Relative direction to traffic

_____ b. Distance to traffic

_____ c. Relative altitude (high-low)

_____ d. Relative altitude (+200, -100)

_____ e. Absolute altitude (1500, 1200)

_____ f. Closing rate

_____ g. Converging - diverging

_____ h. End of conflict

_____ i. Time to closest approach

17. Which formats for the display of the traffic information are the most, and least effective? (1 is most effective, 6 least effective)

_____ a. Warning lights

_____ b. Audio warning tones

_____ c. Digital displays

_____ d. Video displays

_____ e. Synthetic voice warnings

_____ f. Combination of "a. - e." above [specify - ( ), ( ), ( ), ( ), ( )]

[The following statement pertains to Questions 18 through 33]

The reliability of TCAS's position prediction capabilities may be limited by operational procedures which entail sudden and/or frequent heading changes and descent/ascent profiles. Under the column heading "Affect on Reliability" please indicate the extent that TCAS usefulness would be affected while performing the following procedures/operations.

Under the column titled "Safety Enhancement", you are asked to evaluate the overall safety impact of the TCAS on each of the following helicopter mission. As for your comments on "affect on accuracy", answer only for those missions in which you have personal experience. When commenting on the safety impact, assume that the TCAS will be 100% accurate in predicting the position of intruding aircraft.

	AFFECT ON RELIABILITY					SAFETY IMPACT				
OPERATION/PROCEDURE	Greatly Improve	Somewhat Improve	No Effect	Somewhat Limit	Greatly Limit	Improved	No Effect	Degraded	Total Hours Annually	% Of Total Hours
18. Agriculture										
19. Ambulance/Medevac										
20. Construction										
21. Exploration										
22. External cargo										
23. Forestry, general										
24. Fire control, support										
25. Herding										
26. Logging										
27. Offshore										
28 Powerline/Pipeline Patrol										
29. Photography										
30. Pollution Detection										
31. Sightseeing										
32. Traffic Surveillance										
33. Electronic News Gathering										

34. What new type of operations may be made possible by the introduction of TCAS? (describe)

- a. ______________________________
- b. ______________________________
- c. ______________________________

35. If a proven, reliable TCAS were available for purchase today, would you: (check one)

_____ a. Purchase immediately

_____ b. Purchase as soon as economically practical

_____ c. Consider a purchase

_____ d. not purchase

_____ e. no preference

36. How much would you (or your company) be willing to pay for a TCAS system such as you described in Questions 15, 16 & 17? (check one)

_____ a. $1,000. - $2,500.

_____ b. $2,500. - $5,000.

_____ c. $5,000. - $10,000.

_____ d. $10,000. - $50,000.

_____ e. more than $50,000

37. During VFR flight, do you request ATC radar traffic advisories (in areas and altitude with radar coverage)?

_____ a. always (90-100%)

_____ b. often (60-90%)

_____ c. usually (40-60%)

_____ d. seldom (10-40%)

_____ e. never (0-10%)

38. During VFR flight with ATC radar traffic advisories, you receive how many traffic advisories per hour?

____ a. greater than 30 traffic advisories/hr
____ b. 20-30 traffic advisories/hr
____ c. 10-19 traffic advisories/hr
____ d. 5- 9 traffic advisories/hr
____ e. less than 5 traffic advisories/hr

39. During IFR flight, you receive:

____ a. greater than 30 traffic advisories/hr
____ b. 20-30 traffic advisories/hr
____ c. 10-19 traffic advisories/hr
____ d. 5- 9 traffic advisories/hr
____ e. less than 5 traffic advisories/hr

40. Suppose that a TCAS installation is limited in the maximum range at which it can display traffic. At what range would the TCAS have to display traffic in order to provide satisfactory service for helicopter operations

____ nautical miles

41. What fraction of the traffic that passes close enough to be of genuine interest with regard to safest separation is not pointed out to you by ATC?

____ per cent

42. Which altitude (AGL) range do you operate in most often during VFR operations?

____ a. less than 500 feet
____ b. 500-1000
____ c. 1000-1500
____ d. 1500-2000
____ e. 2000-3000
____ f. 3000-5000
____ g. more than 5000 feet

43. In your experience, at what altitude (AGL) do you encounter the most conflicting air traffic?

____ a. less than 500 feet
____ b. 500-1000
____ c. 1000-1500
____ d. 1500-2000
____ e. 2000-3000
____ f. 3000-5000
____ g. more than 5000 feet

44. Would you be willing to participate in a demonstration program of inflight TCAS operations using FAA supplied TCAS avionics?

____ yes ____ no

45. Describe the exact nature of your most recent airborne encounter, to include weather/visibility conditions, traffic environment, type of operation and how the conflict was resolved. (anonymous)

APPENDIX B

FAA DEVELOPED TCAS REQUIREMENTS SURVEY QUESTIONNAIRE

TCAS Form 1

Rotorcraft Environment and Hazard Level

1. Helicopter Make/Model: ______________________

2. Equipment: (check all that apply)

   _____ Transponder
   _____ Altitude Encoder (Mode C)
   _____ Radar Altimeter

3. Primary Operations: (check one)

_____	Agriculture	_____	Law Enforcement
_____	Air Trans, Pt. 135	_____	Logging
_____	Air Trans, Pt. 121	_____	News Gathering
_____	Ambulance/Medevac	_____	Offshore
_____	Construction	_____	Powerline/Pipeline Patrol
_____	Exploration	_____	Photography
_____	External Cargo	_____	Pollution Detection
_____	Forestry, General	_____	Sightseeing
_____	Fire Control	_____	Traffic Surveillance
_____	Herding	_____	Other: _______________

4. Place a '1' in the space for the altitude (AGL) where you normally operate, and a '2' for the altitude where you encounter the most conflicting air traffic.

_____	Less than 200 feet	_____	1500-2000
_____	200-500	_____	2000-3000
_____	500-1000	_____	3000-5000
_____	1000-1500	_____	More than 5000 feet

5. During the past 6 months, how many times have you encountered conflicting air traffic that required some evasive action?

   ____

6. How have you most often maneuvered to avoid collisions?

   _____ a. Vertically   _____ c. Laterally (accel/decel)
   _____ b. Horizontally   _____ d. Combination: ( ), ( ), ( )

7. If there are times when a vertical escape maneuver would not be practical, please explain:
   (e.g. prox. to ground, limited power, etc.)

   ____

TCAS Form 2

Most Recent Near Miss Encounter

1. Your aircraft was: (check each column)

_____	Level	_____	Straight
_____	Climbing	_____	Turning Left
_____	Descending	_____	Turning Right

2. The conflicting aircraft was: (check each column)

_____	Level	_____	Straight
_____	Climbing	_____	Turning Left
_____	Descending	_____	Turning Right

3. Your airspeed: __________

4. Your altitude (AGL): __________

5. Closest approach distance between aircraft: __________

6. You were operating:

_____	VFR, VMC	_____	IFR, VMC
_____	VFR, Marginal VMC	_____	IFR, Marginal VMC
_____	S-VFR, Marginal VMC	_____	IFR, IMC

7. Were you receiving radar advisories at the time?

_____ Yes _____ No

TCAS Form 3

Desired Capabilities

1. What level of alert capability would you desire in a collision avoidance system?

   _____ Advisory
   _____ Caution
   _____ Warning

2. What specific minimum information would you need from the system? (Check all that apply)

   _____ Proximity warning
   _____ Clock position of traffic
   _____ Distance to traffic
   _____ Relative altitude
   _____ Absolute altitude
   _____ Closing rate
   _____ Suggested avoidance action

3. Rank the following formats from most desirable (1) to least desirable (6).

   _____ a. Warning tones
   _____ b. Warning lights
   _____ c. Digital displays
   _____ d. Video displays
   _____ e. Synthetic voice warnings
   _____ f. Comb: ( ) ( ) ( ) ( ) ( )

4. At what range would the TCAS have to display traffic in order to provide satisfactory service?

   ____

5. If a proven, reliable TCAS were available today, would you:

   _____ Purchase immediately
   _____ Purchase when affordable
   _____ Consider a purchase
   _____ Not purchase
   _____ No preference

APPENDIX C

MAKE/MODEL OF HELICOPTER OPERATED BY THE SURVEY GROUP

MAKE		MODEL
Aerospatiale	-	AS-341G
		AS-350D
		AS-355F
		SA-341G
Agusta	-	A-109
Bell	-	BH-47
		BH-47G
		BH-205
		BH-206B
		BH-206BII
		BH-206BIII
		BH-206LI
		BH-206LIII
		BH-212
		BH-222UT
		BH-412
Boeing	-	BV-107
Hughes	-	HU-269A
		HU-269C
		HU-300
		HU-300B
		HU-300C
		HU-500
		HU-500D
Robinson	-	R-22HP
Sikorsky	-	SK-76
		SK-76A
		SK-76A MKII
Westland	-	WG-30