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Field Study Determination of Human Acuity Criteria, Volume 1

Pilot Object Detection Survey

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FOREWORD

This pilot survey of airborne object detection capabilities was performed for Task 29, External Visibility System under contract ZA0229 to Boeing Commercial Airplane Group. The work was funded under contract NAS1-20220 to NASA Langley Research Center (LaRC) covering the period of performance through September, 1996. The NASA LaRC technical monitor for the overall effort was Russ Parrish.

During the preparation of this report technical monitoring was provided by Mike Norman and Lee Summers, XVS Principal Investigators at McDonnell Douglas Aerospace (MDA). Consulting services on operational data in this document was provided by Ken Wells, PPI Aviation Consulting. This report partially fulfills the requirements in the project Statement of Work, Task 29 sub-task 4.11.2.

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SUMMARY

XVS performance of object detection must satisfy the requirements of manufacturers, regulatory authorities, and perhaps most importantly, the users who will rely on this system to accomplish safe transport operations. For successful certification of the High Speed Civil Transport (HSCT), the total XVS/object detection/side window/pilot system will need to demonstrate an equivalent level of safety and visibility to that of existing pilot-window combination. To ascertain what pilots might expect from an external vision system, potential users were approached to elicit expectations of their own object detection capabilities. Two pilot surveys were conducted; the first with FAA (ACO and AEG) pilots, and Douglas Aircraft Experimental and Training pilots. A second survey was conducted with a group of Texas Air National Guard F-16 pilots from the 111th Fighter Interceptor Squadron, most of who are also experienced commercial pilots with major airlines. Both groups were asked to estimate the distance they would "expect" to be able to visually detect and identify airborne targets given visibility out conventional forward looking windows and optimum visual conditions. Estimates were made given clear weather, day and night VFR conditions during a level approach phase. Airborne targets consisted of Transport and General Aviation Category aircraft traveling directly across and directly towards respondent's flight path. Traffic was acknowledged as a result of ATC notifying their aircraft of specific traffic and as a result of normal pilot-not-flying external vision scan. Of the 40 FAA and DAC pilots, most expressed some reservation in providing an absolute distance at which a pilot could detect traffic. This was due to the many factors that impact whether or not traffic is detected in a dynamic operational environment. Therefore, the *distances provided by the pilots surveyed were offered as optimistic estimates of what their "expectations" would be for pilot object detection, given optimum visual and target conditions*.

Both independent pilot groups did not expect ATC called traffic to be visually acquired at greater distances than conditions where the pilot-not-flying is engaged in a focused effort to scan for traffic. Per pilot comments, ATC called traffic does not ensure detection, nor does the use of TCAS. TCAS was referred to as being beneficial in notifying the flight crew of the presence and flight path of

traffic relative to their aircraft, but does not ensure visual detection. Knowing where to look for traffic does not ensure that the pilot will be able to visually acquire the target, even at close range. Even experienced, vigilant pilots report occurrences where, despite their best efforts, traffic is sometimes overshot, missidentified, or not identified at all.

In addition to the distance estimates provided as user expectations for XVS performance, pilots identified at least four specific transition points on the visual continuum that are pertinent to XVS performance. These phases reveal critical transition points that pilots commented on when searching for and detecting traffic using conventional forward facing windows. The first phase is when pilots initially detect a pinpoint of light against the background. The second phase, partial identification, is when the target moves from being a spot to a two-dimensional object. The pilot may be able to tell that it is an airliner but not be able to identify what type. The third phase, occurs when a determination of aircraft type can be made of the target aircraft. As the target approaches closer, the light pattern can clearly be seen and often the aircraft can be seen between the lights. At this point, identification of the aircraft can occur with a high degree of confidence. The fourth phase is close-in or near miss. During close-in situations, what pilots report seeing is very important for determining the best course of action to avoid a midair collision. At this phase the target aircraft is three dimensional (e.g., is the wingtip moving forward in relation to the fuselage or not?). This visual information becomes critical particularly during dynamic situations where seconds count.

Initial visual acquisition and identification phases were addressed in the pilot surveys contained in this report, providing estimates as to what distance pilots expect these phases to occur. As potential users of an external vision system, the pilots surveyed indicated that all of these phases are important and often times critical to their visual task in maintaining situation awareness and accomplishing the “see and avoid” requirement. Their expectation is that these transition points should be present in an XVS and displayed with equal or better resolution than that provided today with conventional windows. The distance at which these phases occur given XVS, should be consistent with the distances expected given conventional windows. These points were considered essential in providing an external visual system with an equivalent level of visibility and safety.

INTRODUCTION

Many factors contribute to what pilots actually see out conventional forward looking windows to accomplish the "see and avoid" requirement. Factors include target characteristics (size, color, contrast), environmental factors (weather, clouds, glare), task variables (such as workload and time at task), and pilot characteristics (fatigue, visual acuity) to name a few. The External Vision System (XVS) for HSCT has the requirement for detection and display of objects. XVS system performance of object detection must satisfy the requirements of manufacturers, regulatory authorities, and perhaps most importantly, the users who will rely on this system to accomplish safe transport operations. For successful HSCT certification, the total XVS/Object detection/side window/pilot system will need to demonstrate an equivalent level of safety and visibility to that of the existing pilot-window combination. An equally challenging requirement for XVS may prove to be user approval and acceptance.

A significant component of pilot acceptability for the HSCT will be the capability of the external vision system to detect and display targets to enable the crew to visually acquire, identify, and avoid them. To ascertain what pilots might expect from an external vision system, potential users were approached to elicit comments and perceptions regarding expectations of their own object detection capabilities .

Pilot Object Detection Survey - Phase I

Phase I Conditions

Experienced pilots were asked to estimate the distance they would "expect" to be able to detect airborne targets, identify these targets, and take normal corrective action to safely avoid the potential hazard, given visibility out conventional forward looking windows and optimum visual conditions. Estimates were made given clear weather, day and night VFR conditions, during a level approach phase between 10,000 and 18,000 feet. Airborne targets consisted of aircraft traffic traveling directly across their flight path and directly towards their aircraft, with normal aviation lights illuminated. Traffic was classified into three general categories: Widebody aircraft such as B747s and MD-11 s, Narrowbody aircraft such as MD-80/90s and B737s, and General Aviation aircraft, for daytime conditions. Widebody and Narrowbody aircraft were combined into a single Transport category for nighttime conditions. Traffic was acknowledged as a result of ATC notifying their aircraft of specific traffic (Oriented visual search), and as a result of a normal pilot-not-flying external vision scan (Random visual search), with no prior warning. Oriented and Random search conditions were presented to pilots in a counterbalanced manner to account for possible order effects.

Phase I Respondents

Pilots with extensive operational experience were approached because they are well suited to providing information on their experience with respect to seeing and avoiding traffic. Experienced pilots are therefore a logical, first step for obtaining estimates on what their expectations would be for object detection capabilities for an external vision system. Douglas Aircraft Company Training and Experimental pilots, along with FAA Aircraft Certification Office (ACO) and Aircraft Evaluation Group (AEG) pilots from the Long Beach FAA office were surveyed. All of the respondents primary background was in military and/or commercial aviation. Approximate commercial flight hours ranged from 600 to 16,500 hours, with an average of 4700 commercial flight hours. Approximate total pilot hours ranged from 5000 to greater than 20,000 hours, with an average total time of 8900 flight hours.

Phase I (FAA and DAC pilot) Results

Before reviewing the data, a note on the pilot comments received is warranted. Of the 40 respondents, most expressed some reservation in providing an absolute distance at which a pilot could detect traffic. The primary reason for this was the recognition of the many factors that effect whether an aircraft is detected or not in an operational environment. Experienced pilots are acutely aware of the variability in object detection performance across pilots and varying situations. They recognize the large number of variables that impact detection and the complexity and difficulty involved in predicting pilot performance. However, respondents were willing to provide estimates on what their "expectations" would be given optimum visual and target conditions. A frequent comment from respondents was how often traffic is missed in a dynamic, busy operational environment, even with an ATC call. With the addition of TCAS to the flight deck, pilots commented on their increased level of awareness to the amount of traffic around them. However, awareness does not ensure successful visual detection. Respondents candidly admitted to experiences where the wrong traffic was sighted; other accounts included occurrences of passing traffic and never seeing it, even on a clear day. The distances provided were therefore offered as *optimistic estimates of expectations for pilot detection capabilities.*

Random versus Oriented Search on Acquisition Distances

There was essentially no difference found between pilot's acquisition estimates (i.e., distances) given their routine visual scan (Random Search) and the conditions where ATC notified their aircraft of specific traffic (Oriented Search). Given the assumption of optimum visual conditions, pilot's expectations of their own capabilities were comparable for the two scan conditions, and were not dependent on search strategy. Random versus oriented search strategy differences may exist for latency to detect and percentage of traffic detected, but did not influence distance at which pilot’s expected to initially acquire the target aircraft. Therefore, Random and Oriented visual scan conditions were combined.

Size of Target Aircraft on Acquisition Distances

Distances at which pilots detected targets did vary based on size of target. Pilots expect to be able to initially detect Widebody and Narrowbody aircraft at greater distances than General Aviation aircraft. Distance to visually acquire Narrowbody aircraft closely aligned with estimates for Widebody aircraft with a noticeable shift (lower) in expected acquisition distances across all conditions for General Aviation aircraft targets. General Aviation aircraft were visually acquired at closer distances in comparison to transport aircraft. Due to the lack of difference found between Widebody and Narrowbody acquisition estimates, these two categories were combined into a single "Transport" aircraft category for contrast with General Aviation targets for the daytime conditions. Nighttime conditions were originally combined into these same two target categories.

Distances for Visual acquisition of aircraft traffic - Daytime conditions

Pilots' expectations for visual acquisition of Transport aircraft traffic during daytime VFR conditions ranged from 10 - 1 miles. Transport aircraft traveling directly towards respondents' aircraft was expected to be visually acquired between 10 -1 miles out, with the most frequent responses being 2, 3 and 4 miles. For Transport aircraft approaching across respondents' flight path, estimates ranged from 10 - 3 miles, with 5 miles being the most frequent response.

Pilots' expectations for visually acquiring General Aviation aircraft ranged from 5 - 0.5 miles. General Aviation aircraft traveling directly towards respondents' aircraft was expected to be acquired between 2 - 0.5 miles, with 2 miles being the most common estimate. For acquiring General Aviation traffic approaching across respondents' flight path, estimates increased in range from 5 - 1 miles, with 3 miles being the most common estimate.

The frequency distribution of distance estimates for visually acquiring Transport and General Aviation aircraft during daytime conditions, are shown in Figure 1 and Figure 2 respectively. Figure 1 and 2 also show response differences as a function of traffic approach path (towards versus across respondents' flight path).

Distances for Visual acquisition of aircraft traffic - Nighttime conditions

Overall, pilots' expectations for visual acquisition of aircraft traffic at night ranged from 50 - 3 miles for Transport aircraft and 30 -1 miles for General Aviation aircraft. However, the most frequent response for acquiring Transport aircraft traveling directly toward the respondent's aircraft was 3 and 5 miles, and 5 miles for Transport aircraft approaching across respondents' flight path. The most frequent estimate for visually acquiring General Aviation aircraft traffic regardless of approach path was 2 miles.

Figure 3 shows the distribution of distance estimates for visually acquiring Transport Category aircraft at night given that the traffic is traveling towards or across the respondents' flight path. Figure 4 shows the distribution of distance estimates to visually acquire General Aviation aircraft traffic at night, given the same traffic approach conditions (towards or across respondents flight path).

Expected Distances to Identify Transport and General Aviation Category Traffic

As shown in Figure 5, pilots responded that they would expect to identify Transport aircraft during daytime, VFR conditions, between 10 - 1 miles. The most frequent responses were for 2, 3, and 4 miles. As shown in Figure 6, pilots expected to be able to identify General Aviation aircraft traffic during daytime VFR conditions, from 4 - 0.25 miles out, with the highest frequency of responses at 2, 1 and 0.5 miles respectively. At night the picture changed considerably. As shown in Figure 7, estimates for identifying Transport Category aircraft traffic ranged from 5 - 0 miles. As shown in Figure 8 estimates for identifying General Aviation Category aircraft traffic ranged from 2 - 0 miles. For both groups of airborne targets, the highest frequency response was zero miles (unable to identify).

Expected Distances to Perform Normal Corrective Action

Although corrective action distances provided by respondents may not be applicable to HSCT due to performance characteristics and aircraft differences, they are provided here for completeness. In general, during daytime VFR conditions, pilot expectations for performing a normal corrective action maneuver (not an escape maneuver) to avoid detected traffic, ranged from 8 miles to 0.25 mile. Figure 9 shows the distribution of distance estimates to perform normal corrective action given Transport Category aircraft traffic for daytime, VFR conditions. Figure 10 shows the distribution of distance estimates to perform normal corrective action given General Aviation Category aircraft traffic for daytime, VFR conditions.

For nighttime VFR conditions, pilots expected to be able to perform a normal corrective action maneuver to avoid all types of traffic between 5 and 0.5 miles. The most common responses for both Transport and General Aviation aircraft traffic, were for 1 and 2 miles. Distributions for expected distance needed to perform normal corrective action for Transport and General Aviation Category aircraft traffic at night are shown in Figure 11.

Phase I Discussion

Pilot respondents expected to acquire Transport aircraft at greater distances than General aviation aircraft. However, they did not expect their object detection performance with ATC called traffic to be more successful in general than randomly scanning for traffic. ATC called traffic can facilitate timely detection of traffic, but it is no guarantee. According to these experienced commercial pilots, their are more salient factors (such as lighting) that ultimately effect what pilot's can see out forward facing windows. The same can be stated for TCAS, which will notify pilots of the presence and general location and trend of traffic.

However, knowledge that traffic exists and where to look in general, does not always ensure detection. Visual acquisition of traffic is dependent on many other factors.

In general, traffic was expected to be acquired within 10 miles for daytime conditions. At night, expectations increased to 20, 30, and up to 50 miles for detection, depending on the lighting conditions. This increase was attributed to aircraft lighting at night. Although the most frequent estimate for acquiring aircraft at night was in the 2 to 5 mile range, this was generally stated as providing adequate distance to perform a normal corrective action if required. When it comes to the identification of traffic at night, most pilots did not expect to be able to identify aircraft type, regardless of size and approach path. To explore this area more thoroughly, a second sample of expert pilots were consulted for their comments on expected pilot object detection capabilities.

Pilot Object Detection Survey, Phase II

Phase II Respondents

A group of Texas Air National Guard F-16 pilots from the 111th Fighter Interceptor Squadron were consulted to provide an independent assessment of pilot's expected see and avoid capabilities. These pilots are uniquely skilled at searching and identifying other aircraft.

The 111th Fighter Interceptor Squadron's mission is to defend the airspace along the southern portion of the United States. Because of this, they only have an air-to-air intercept mission. They routinely intercept, and fly in close proximity to unidentified aircraft entering the southern Air Defense Identification Zone. The intercepted aircraft range from oil rig helicopters and drug smuggling Cessnas, to commercial 747's that are 5 minutes late at an Air Defense reporting point. Some intercepts occur at night with unidentified aircraft not displaying external lighting. The skills required to perform a high speed intercept and rejoin on another possibly uncooperative aircraft, make Air Defense F-1 6 pilots very aware of visual distances at which airborne targets can be seen and identified. In addition to their Guard duties, most of the surveyed pilots are currently employed as commercial pilots with major airlines.

Phase II Conditions

Similar to Phase I, pilots were asked to provide estimates of the distance expected to visually acquire and identify airborne targets. Three airborne targets were specified: a Northwest 747-400, an American MD-80, and a White Cessna 172. Each target aircraft was presented as being at the same altitude as respondents aircraft (10,000 feet), located between 11 and 1 o'clock and approaching directly towards or perpendicular to them. Estimates were made given clear weather, VFR conditions with unlimited visibility, during daytime (noon) and nighttime conditions. In addition, Guard pilots were encouraged to provide written comments.

Phase II (Air National Guard Pilot) Results

The general characteristics of the data received by the Guard pilots can be generally described as more precise and consistent compared to Phase I data. In Phase 1, the pilots as a group considered Widebody and Narrowbody aircraft as one transport category. There were no differences found in acquisition or identification distances between the two. In contrast, the Guard pilots as a group, consistently broke out these two types of aircraft and provided estimates commensurate with aircraft size. As in Phase I, there was no difference found for search strategy. Guard pilots made no distinction in distance estimates for acquiring and identifying targets based on ATC called traffic between the 11 and 1 o'clock position and their normal pilot scan out the windows for targets between 11 and 1 o'clock. Therefore, these two conditions were collapsed into a single category for review of other trends across conditions (i.e., time of day, target size and direction of approaching traffic).

Table 1 summarizes the Air National Guard F-1 6 pilot estimates for visual acquisition and identification of the three airborne targets. For each day and night condition, Table 1 shows the minimum, maximum and highest frequency response for each target given an approach path perpendicular and directly towards respondent's aircraft flight path.

<u>Target Size and Approach Path on Visual Acquisition and Identification Estimates</u>

As depicted in table 1, target size and approach path affected the distance at which pilots expected to be able to visually acquire and identify the target. Across all conditions, pilots expected to acquire the larger 747 aircraft at the greatest distances followed by the MD-80 and Cessna 172. This trend was particularly clear for daytime conditions, but was also found for nighttime conditions as well.

With regard to identifying the target aircraft, there was a consistent difference found in the estimates between the 747, MD-80 and Cessna across conditions. The larger the target, the farther away pilots expected to be able to identify it, given daytime VFR conditions. This trend did not hold true for nighttime conditions. At night, the majority of pilots stated that a visual identification of the airborne target was not expected. Additional pilot comments were received discussing nighttime visual conditions and pilot expectancies. These will be addressed in the Discussion Section.

With regards to target approach path, a trend was found across all conditions with the exception of the identification of traffic at night. In general, distances to acquire and identify (daytime only) targets were greater for traffic approaching perpendicular to respondent's flight path, and less for the same target approaching directly towards respondent's aircraft. This would follow since a perpendicular approach path would afford pilots a larger target aspect ratio compared to targets approaching directly towards them.

Time of Day on Visual Acquisition and Identification of Airborne Traffic

The range of distances to acquire aircraft were much larger for nighttime conditions compared to daytime. This could be attributed to the benefits of aircraft lighting in the detection of traffic at night, allowing targets to be spotted at great distance. Differences in distance estimates found between daytime and nighttime conditions were dependent on the specific pilot task. As shown in Table 1, the main trends of target size and approach path (aspect ratio) were found to be consistent across daytime and nighttime visual acquisition estimates, and daytime identification estimates. They did not hold true for Nighttime identification estimates. At night, the data indicated a clearly different environment for pilots to accomplish a visual identification task; most of the pilots did not expect to be able to identify traffic regardless of target size and approach path.

Expected Distances for Visual Acquisition of Airborne Traffic

As shown in Table 1, with good visibility at high noon, pilots expected to visually acquire airborne traffic approaching perpendicular to their flight path in the range of 40 - 10 miles for the 747-400, 20 - 7 miles for the MD-80, and 10 - 2 miles for the Cessna 172. When these aircraft approached directly towards them, estimates were reduced to 15 - 6 miles, 10 - 4 miles, and 7 - 2 miles, respectively.

With good visibility at night, pilots expected to acquire the 747, MD-80, and Cessna approaching perpendicular the their flight path in the range of 40 - 10 miles, 40 - 6 miles, and 25 - 2 miles, respectively. When these aircraft approached directly towards them, pilots adjusted their acquisition estimates to 40 - 5 miles for both 747 and MD-80, and 25 - 0.5 miles for the Cessna.

Expected Distances for Identification of Airborne Traffic

For daytime conditions, pilots expected to be able to identify the 747, MD-80 and Cessna 172 approaching perpendicular to their flight path in the range of 15 - 4 miles, 10 - 2 miles, and 5 - 0 miles, respectively. When these aircraft approached directly towards them, estimates were reduced to 10 - 3 miles, 7 - 0 miles, and 6 - 0.5 miles, respectively.

For nighttime conditions, pilots' expectations for the identification of these targets when approaching perpendicular to their flight path, ranged from 8 - 0 miles for the 747, 6 - 0 miles for the MD-80, and 4 - 0 miles for the Cessna 172. When these aircraft approached directly towards respondents' aircraft, expected distances were reduced to 5 - 0 miles for *all three targets.* The most frequent response was zero; 43% to 71% of the pilots (depending on the condition) responded that they would not expect to be able to identify these airborne targets at all for nighttime conditions, regardless of target size and approach path.

Air National Guard Pilot Comments

- Additional comments received from the Guard pilots that are pertinent to the task of the external vision system are included here for review and information. Comments are provided verbatim in bullet form for ease of review.
- Detection is of course most important . ID is not a requirement for safe avoidance, but identification of aspect ratio (path) is. Pilot needs to judge relative heading and line of sight rate for successful avoidance. At night, strobe lighting can be seen 360 degrees around the aircraft with a minimum of 550 candle power. On a clear night they are easily visible from 25 miles regardless of aspect. Colored position lights make aircraft aspect easily recognizable, but only within a mile or two.
- Identifying an aircraft is not normally a necessity unless you are going to follow it in a visual approach (i.e., "you are cleared the visual approach behind the MD-88"). A pilot would have to devote complete attention to clearing for aircraft, at the detriment to other duties, to get a tally (visual sighting) of an unreported aircraft consistently. A fighter style Target Designator Box (TD box) in the HUD of a fighter **greatly** enhances a tally.
- A pilot friendly visual acquisition system would consist of TCAS warnings displaying a square TD box in a HUD to aid acquisition. The TD box should remain in view until the TCAS advisory goes away. An ATC traffic advisory would result in a TD circle in the HUD to aid acquisition. The circle should have a cancel feature when you acknowledge a tally.

General Discussion - Phase I and II

Both independent pilot groups did not expect ATC called traffic to be visually acquired at greater distances than conditions where the pilot-not-flying is engaged in a focused effort to scan for traffic. These experienced pilots recognize the significant number and influence other factors have in determining whether traffic is visually detected or not. ATC called traffic does not ensure detection, nor does the use of TCAS. Although TCAS was not addressed specifically in the methodology of these pilot surveys, respondents who are also commercial pilots, currently fly with the benefit of TCAS on their respective flight decks. Per pilot comments, TCAS was referred to as being beneficial in notifying the flight crew of the presence and flight path of traffic relative to their aircraft, but does not ensure visual detection. Knowing where to look for traffic does not ensure that the pilot will be able to visually acquire the target, even at close range. Whether the pilot sees the traffic or not in a dynamic operational environment, was perceived by pilot respondents to be largely influenced by lighting conditions and aspect ratio. In addition, even experienced, vigilant pilots report occurrences where, despite their best efforts, traffic is sometimes overshot, missidentified, or not identified at all.

Object detection, recognition and identification are not discreet events but rather fall on a continuum in the visual acquisition process. Pilot written and verbal comments focused on four discrete events or phases on this continuum that are of interest to XVS. These phases reveal critical transition points that pilots commented on when searching for and detecting traffic in flight using conventional forward facing windows. They are the points were pilots, initially see a target, partially identify the target, identify, and near miss another aircraft in flight. At each of these points or phases, commercial pilots report using the information obtained visually to assess the situation and accomplish "see and avoid".

1) The first point or phase addressed in pilot comments and follow-up discussions is when a pilot detects a pinpoint of light against the background. When a pilot first sees another aircraft it may be no more than a spot. If observing another airliner, the distance may be 10 miles or more during the day. At night this point source of light may be detected as far away as 20, 30 or even 50 miles under the best of conditions. Normally pilots do not make much use of this information, except in abnormal situations where it can be vitally important. For example, in the event of the loss of radar facilities by enroute air traffic control. When this occurs during cruise conditions, pilots become extremely vigilant and scan outside the aircraft to the limits of their visibility. The first hint of a traffic conflict may come from observing another aircraft at long distance in the "wrong" place.

2) Partial identification. As the object approaches closer, the target aircraft moves from being a spot to a two-dimensional object. The pilot may be able to tell that it is an airliner but not be able to identify what type. During optimum daylight conditions, this may occur at a distance of approximately 10

miles. At night, partial identification occurs when a point source of light starts to break up into two or more point sources that comprise the aircraft's external lighting system. Depending on the targets heading and flight path, the light sources may not be defined enough to present a recognizable light pattern.

Pilots routinely use this information for situation awareness in the downwind traffic pattern. If other aircraft are two-dimensional objects (rather than a single point source), they can be observed banking into turns and starting descents. This information can be interpreted much quicker than current TCAS data. Pilots can also use this visual information to determine their own aircraft configuration and airspeed in an effort to optimize performance and fuel economy which directly effects airline profitability.

3) Identification of airborne traffic. For the purposes of this survey, identification occurs when a determination of aircraft type can be made of the target aircraft. As a target approaches even closer, the light pattern can clearly be seen and often the aircraft can be seen between the lights. At this point, identification of the aircraft can occur with a high degree of confidence. During the daytime, this can happen at approximately 5 miles. At night the target aircraft's external pattern of lights are distinguishable and may allow identification of aircraft type, but at much closer distances.

Air traffic control routinely requests pilots to use this information to follow specific aircraft to the airport. To accomplish this ATC request, a pilot must confirm that he or she can identify the preceding aircraft to the Air Traffic Controller. The majority of pilot comments addressed the issue of what exactly constitutes "identification" and when does this typically take place, particularly at night. Pilots commented that they often make assessments about the target's type based on recognizable light patterns, but without further clarification on the survey, responded with low expectations for the identification of aircraft at night with any consistency.

4) Close-in or near miss. This was arbitrarily defined as anytime one aircraft unintentionally gets within 0.5 mile of another aircraft. During these close-in situations what pilots report seeing is very important for determining the best course of action to avoid a midair collision. Sometimes the crew will be aware of the problem before being alerted by TCAS. At distances of less than 0.5 mile, the target aircraft gets very three dimensional. This is important because the avoidance task at close distance is influenced by where the different parts of the aircraft are in reference to each other (e.g., is the wingtip moving forward in relation to the fuselage or not?). At night, the aircraft can be seen within the light pattern, and sometimes window lighting. During the daytime, pilots may even be able to see the other flight crew. A likely area for near misses is on final approach at airports that have multiple parallel runways.

Overshoots can occur for multiple reasons. During this dynamic situation, especially if TCAS avoidance is not possible (e.g., descent command when terrain clearance is in question), the visual interpretation of the other aircraft's position and intentions is vital to avoiding a midair collision.

The expectation of pilots surveyed is that all of these phases are important and often times critical to their visual task in accomplishing the "see and avoid" requirement. Whether forward facing windows are used or a simulated external visual system, the pilot's task is the same; visual information is used for situation awareness. Therefore these visual elements should be represented in an external visual system and implemented to provide an as-good-as or better system, than what is provided today in current aircraft with forward facing windows. The distance at which these phases occur given XVS, should be consistent with the distances expected given conventional windows. For example, when a point source of light in the distance breaks out into a pattern of light, XVS should present this pattern at the approximate distance it would occur today using conventional windows. Similarly, during close-in dynamic situations, the visual interpretation of the other aircraft's position and intentions should be represented in an XVS system in real-time where seconds can make a difference between a near miss and a mid-air collision.

Conclusion

With regard to the "see and avoid" requirement, the conditions surveyed and the resulting detection estimates are by no means exhaustive and comprehensive. However, the estimates provided by the two, experienced and independent potential user groups, were remarkably similar and can provide insight into general user expectations for an external vision system. These estimates provide a reality check for certain aspects of XVS performance responsibilities and can serve as validation criteria for an external vision system. Pilot expectations for the external vision system performance will influence user approval and overall operational acceptability of the HSCT.

Over and above the distance estimates provided as pilot expectations for XVS performance, pilot comments regarding detection and identification warrant further discussion and investigation. Pilots identified at least four specific transition points on the visual continuum which are key to their visual task using forward facing windows. Their expectation is that these critical transition points should be present in an XVS and displayed with equal or better resolution than that provided today with conventional windows. The distance at which these phases occur given XVS, should be consistent with the distances expected given conventional windows. These points were considered essential in providing an external visual system with an equivalent level of visibility and safety.

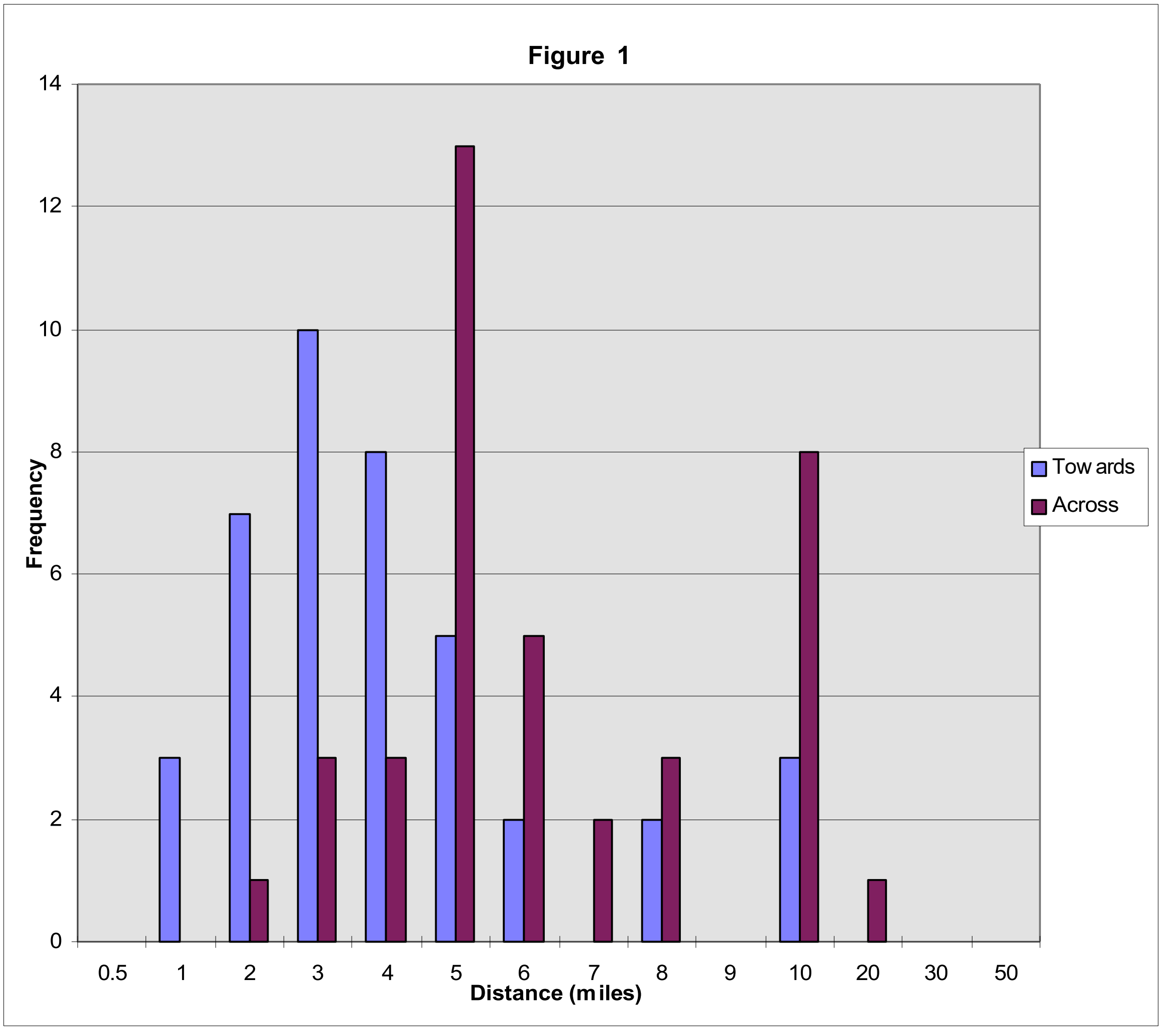

Figure 1. (n = 40) FAA/DAC pilot estimates for expected distance to visually acquire Transport Category aircraft. Conditions were for daytime, VFR with unlimited visibility at 10-18K feet and Transport Category aircraft traffic approaching directly towards and across respondent's flight path.

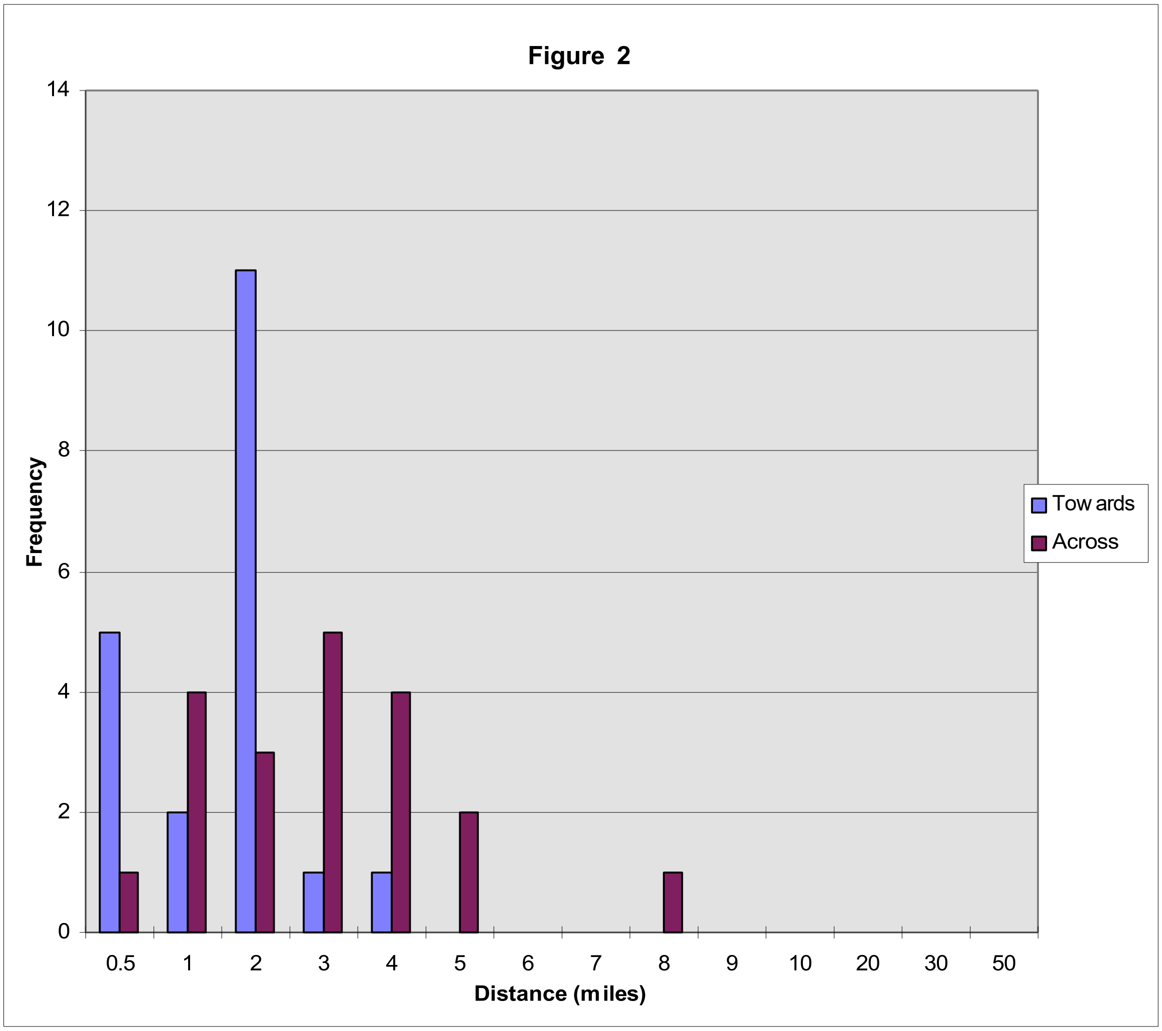

Figure 2. (n = 20) FAA/DAC pilot estimates for expected distance to visually acquire General Aviation Category aircraft. Conditions were for daytime, VFR with unlimited visibility at 10-18K feet, and General Aviation aircraft traffic approaching directly towards and across respondent's flight path.

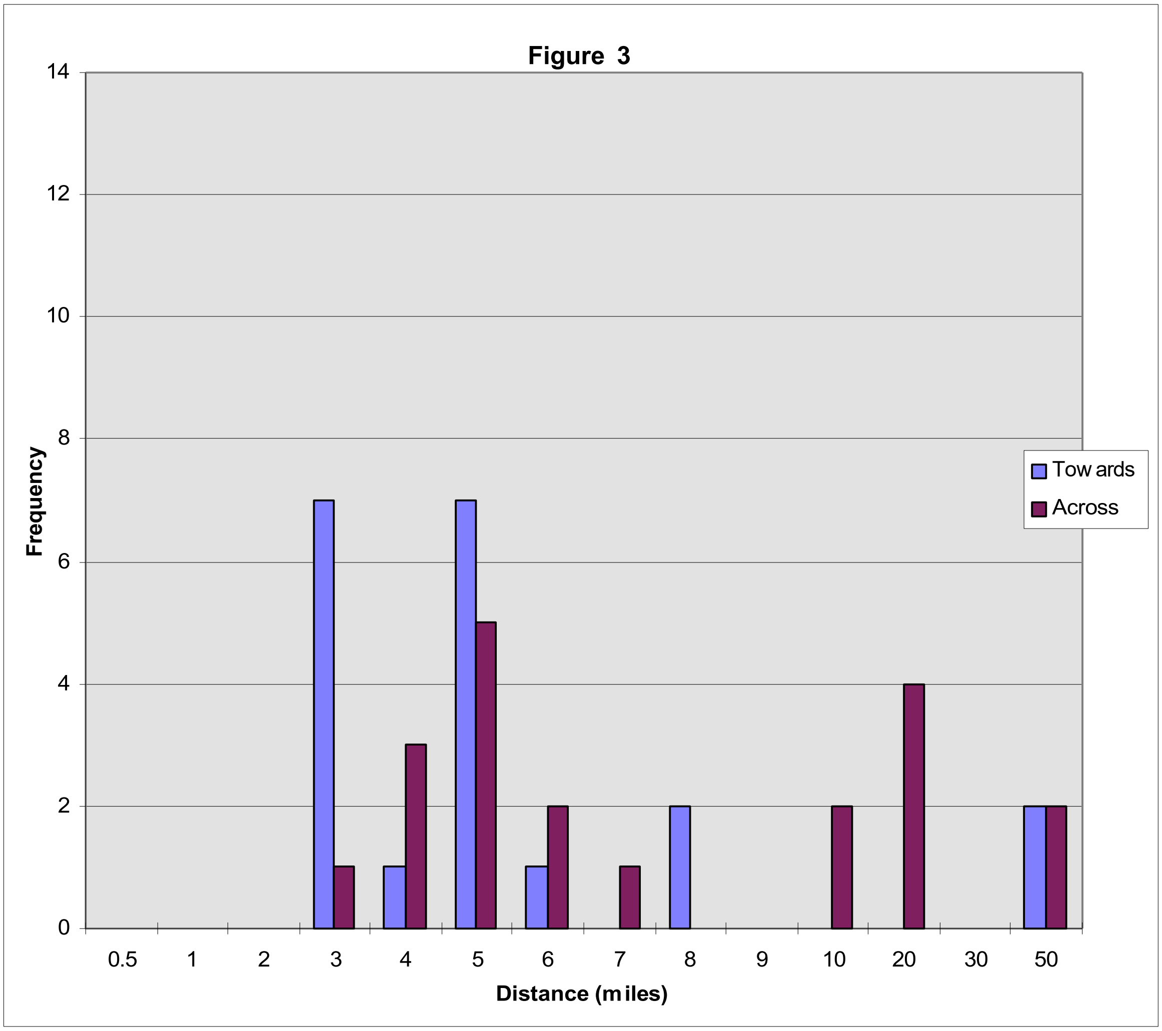

Figure 3. (n = 20) FAA/DAC pilot estimates for expected distance to visually acquire Transport Category aircraft. Conditions were for nighttime, VFR with unlimited visibility at 10-18K feet, and Transport Category aircraft traffic approaching directly towards and across respondent's flight path.

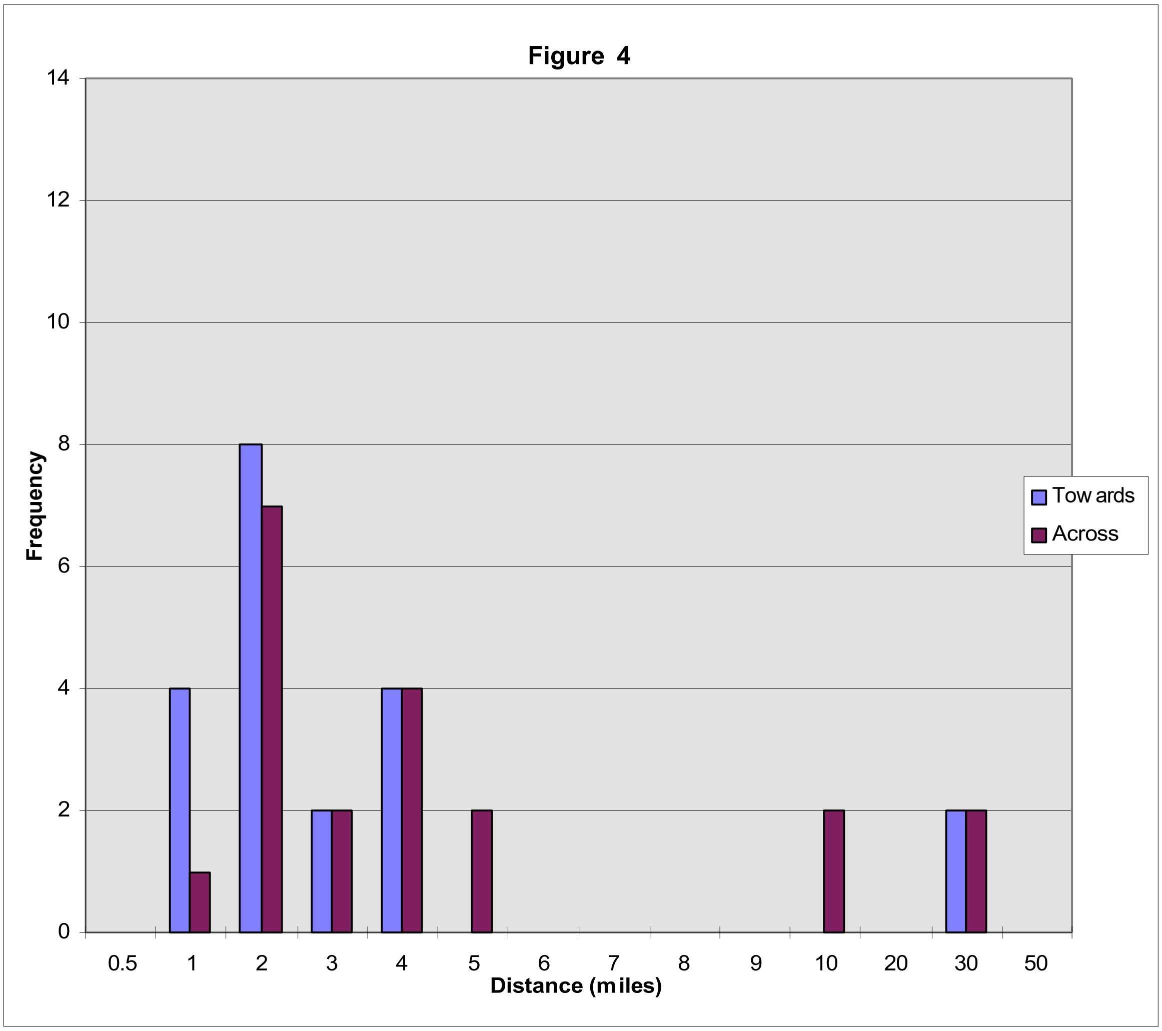

Figure 4. (n = 40) FAA/DAC pilot estimates for expected distance to visually acquire General Aviation Category aircraft. Conditions were for nighttime, VFR with unlimited visibility at 10-18K feet, and General Aviation aircraft traffic approaching towards and across respondent's flight path.

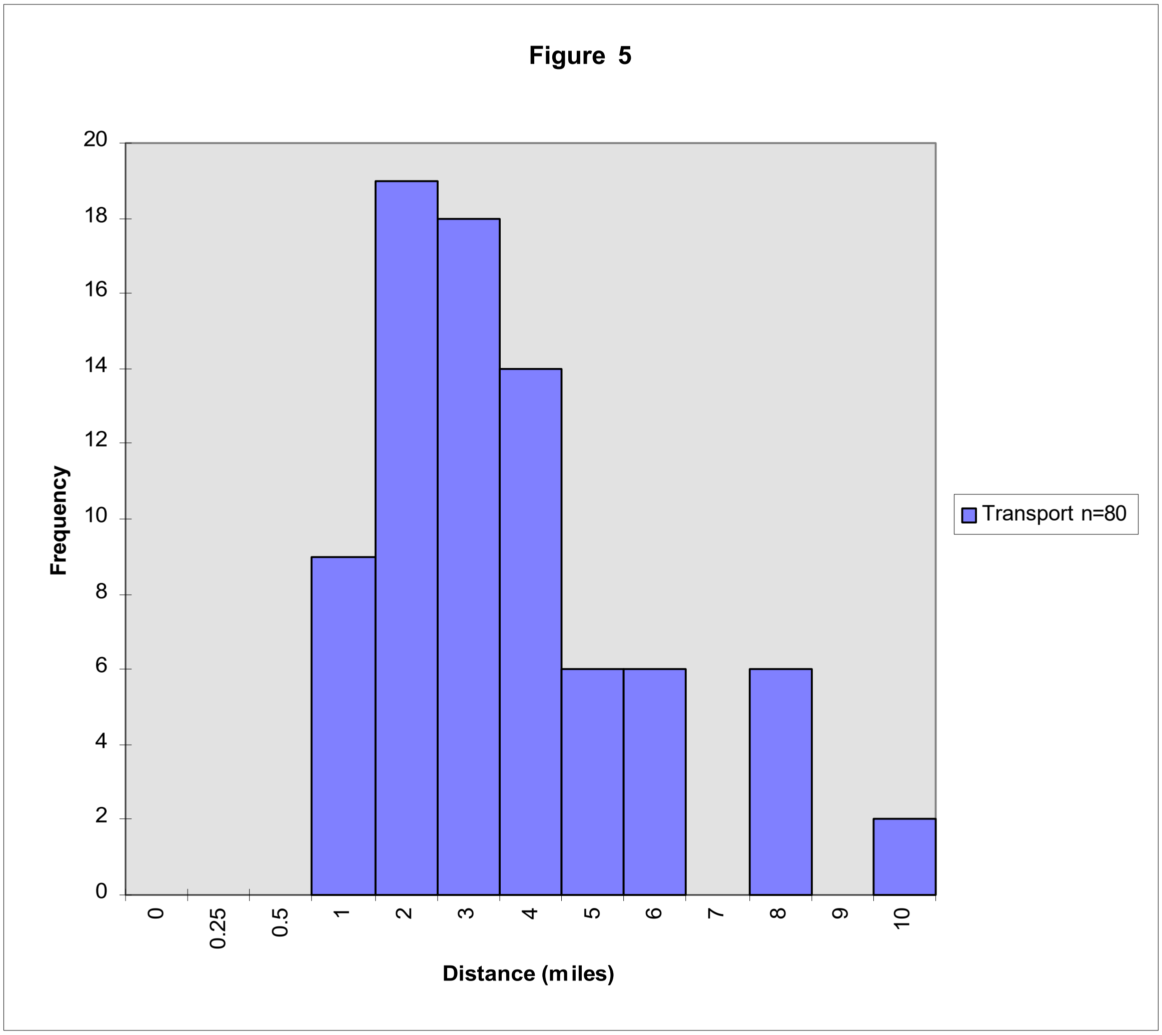

Figure 5. (n = 80) FAA/DAC pilot estimates for expected distance to visually identify Transport Category aircraft traffic during daytime, VFR conditions.

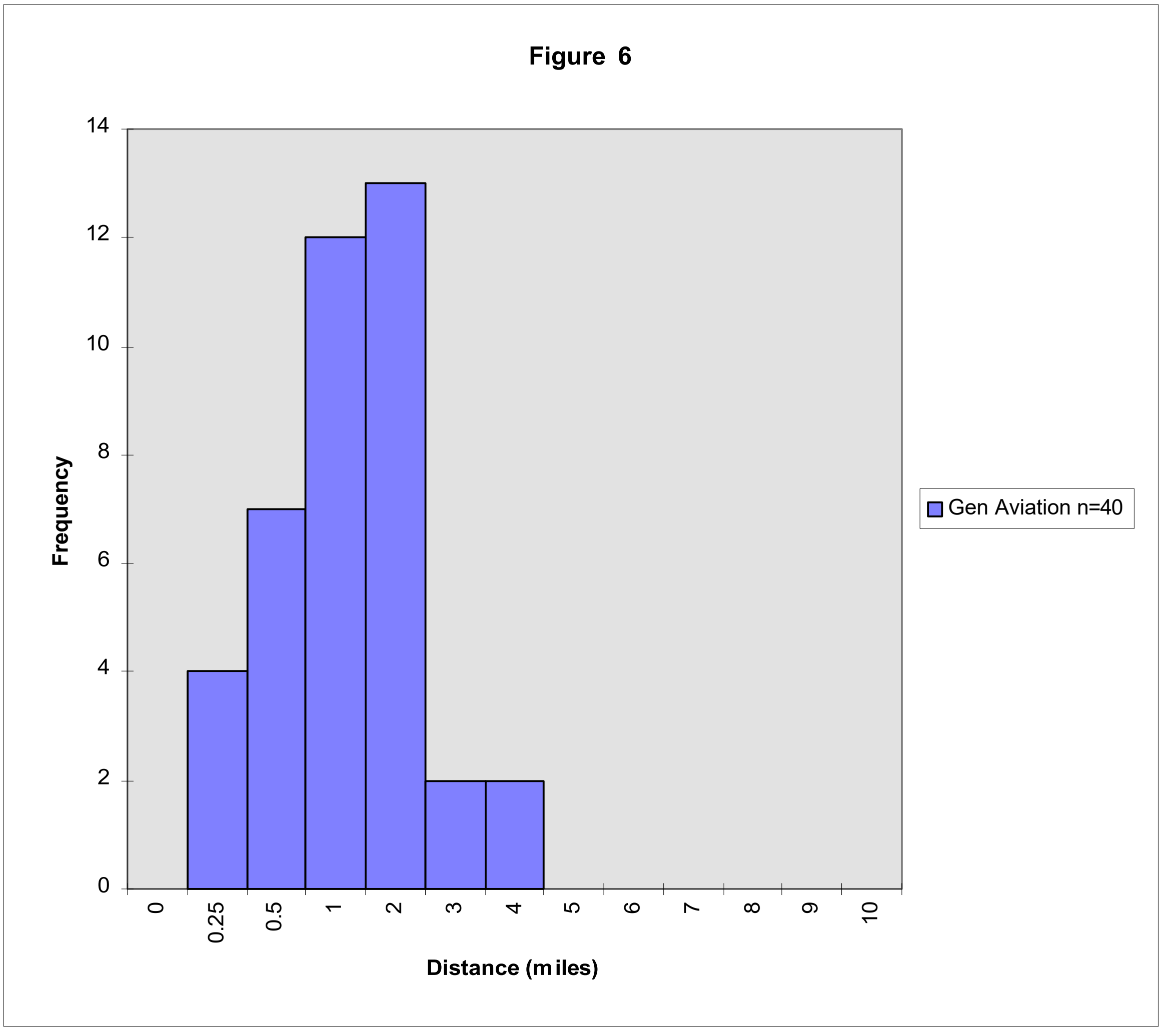

Figure 6. (n = 40) FAA/DAC pilot estimates for expected distance to visually identify General Aviation Category aircraft traffic during daytime VFR conditions.

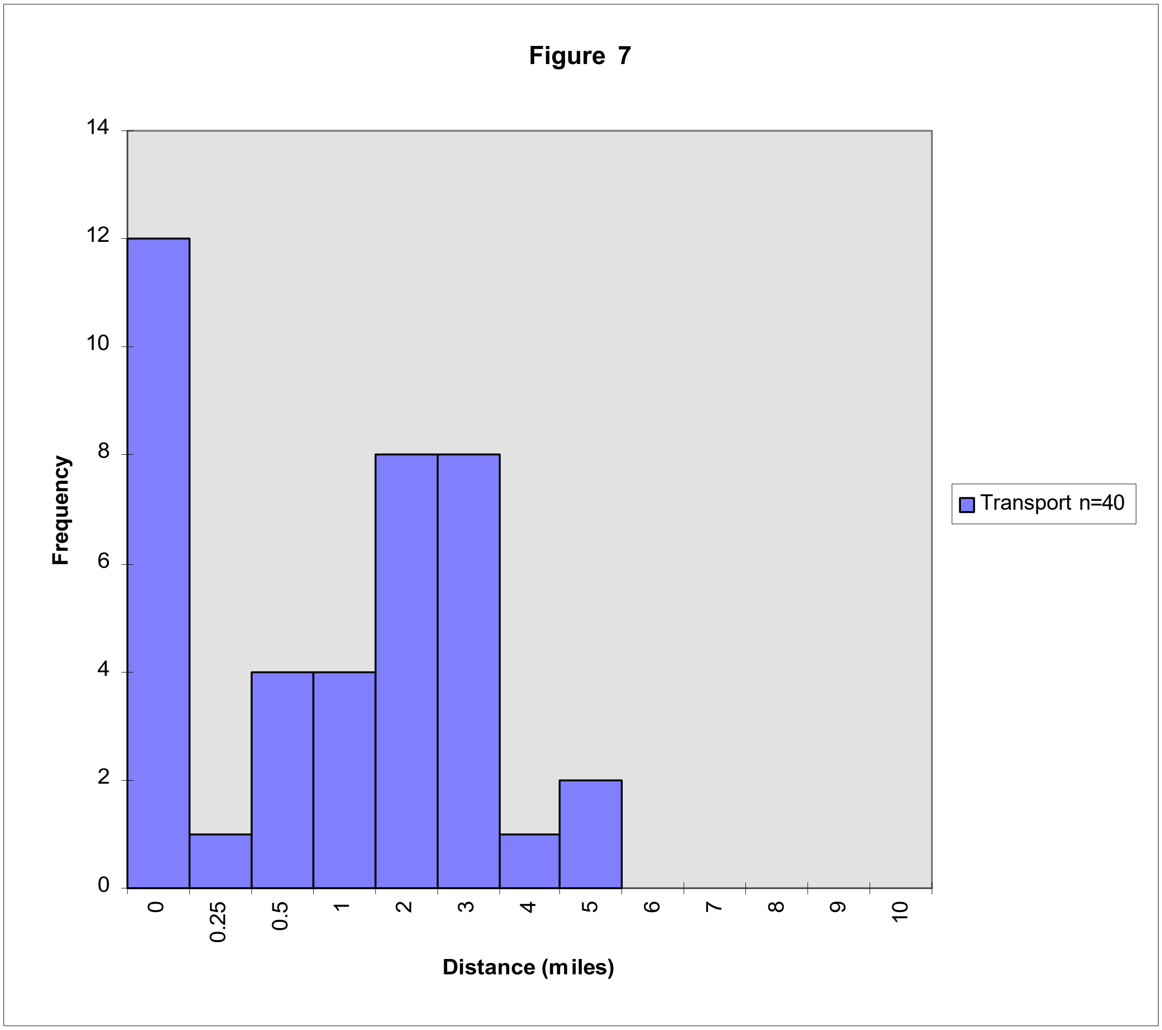

Figure 7. (n = 40) FAA/DAC pilot estimates for expected distance to visually identify Transport Category aircraft traffic during nighttime, VFR conditions.

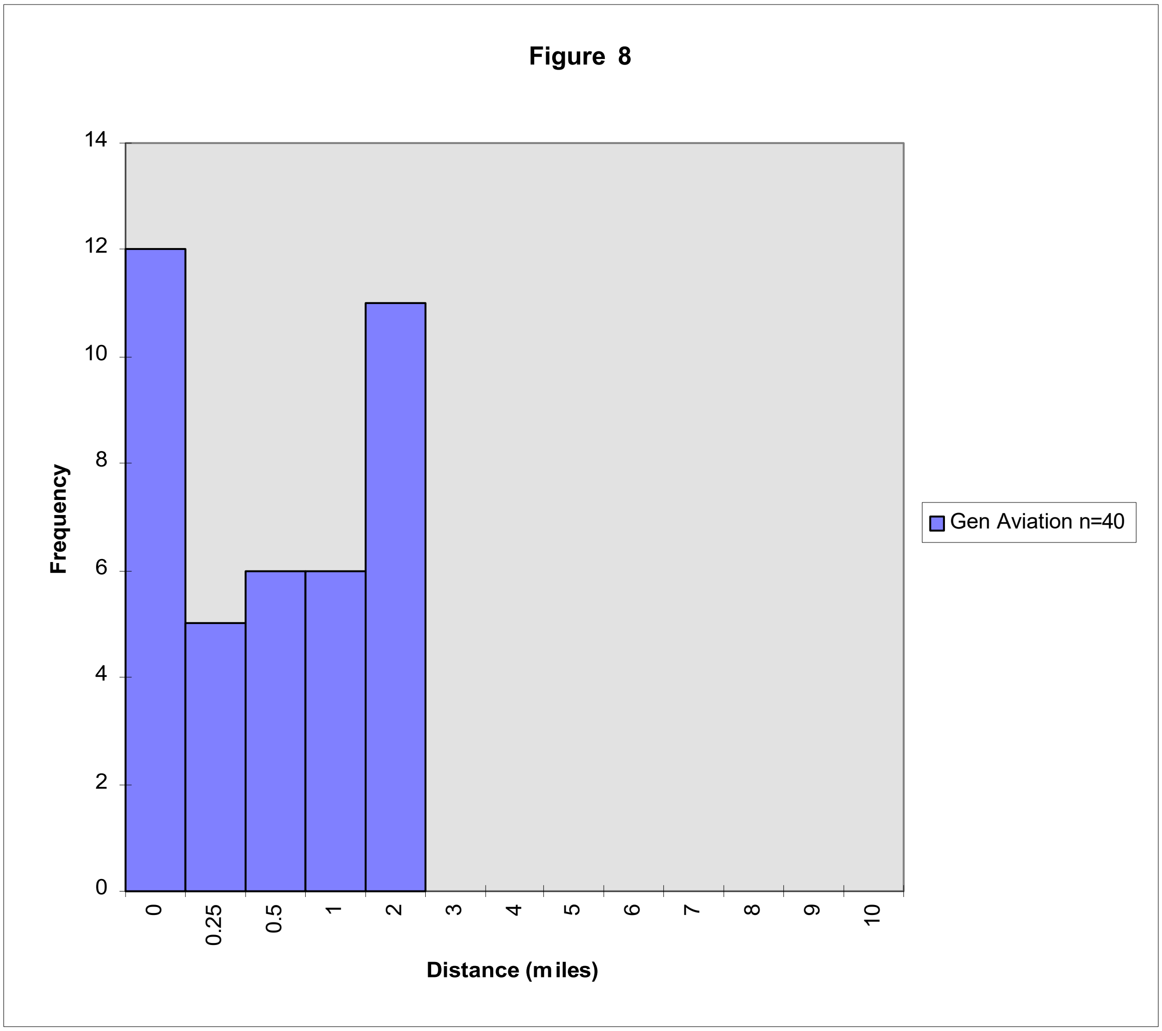

Figure 8. (n = 40) FAA/DAC pilot estimates for expected distance to visually identify General Aviation Category aircraft traffic during <u>nighttime</u>, VFR conditions.

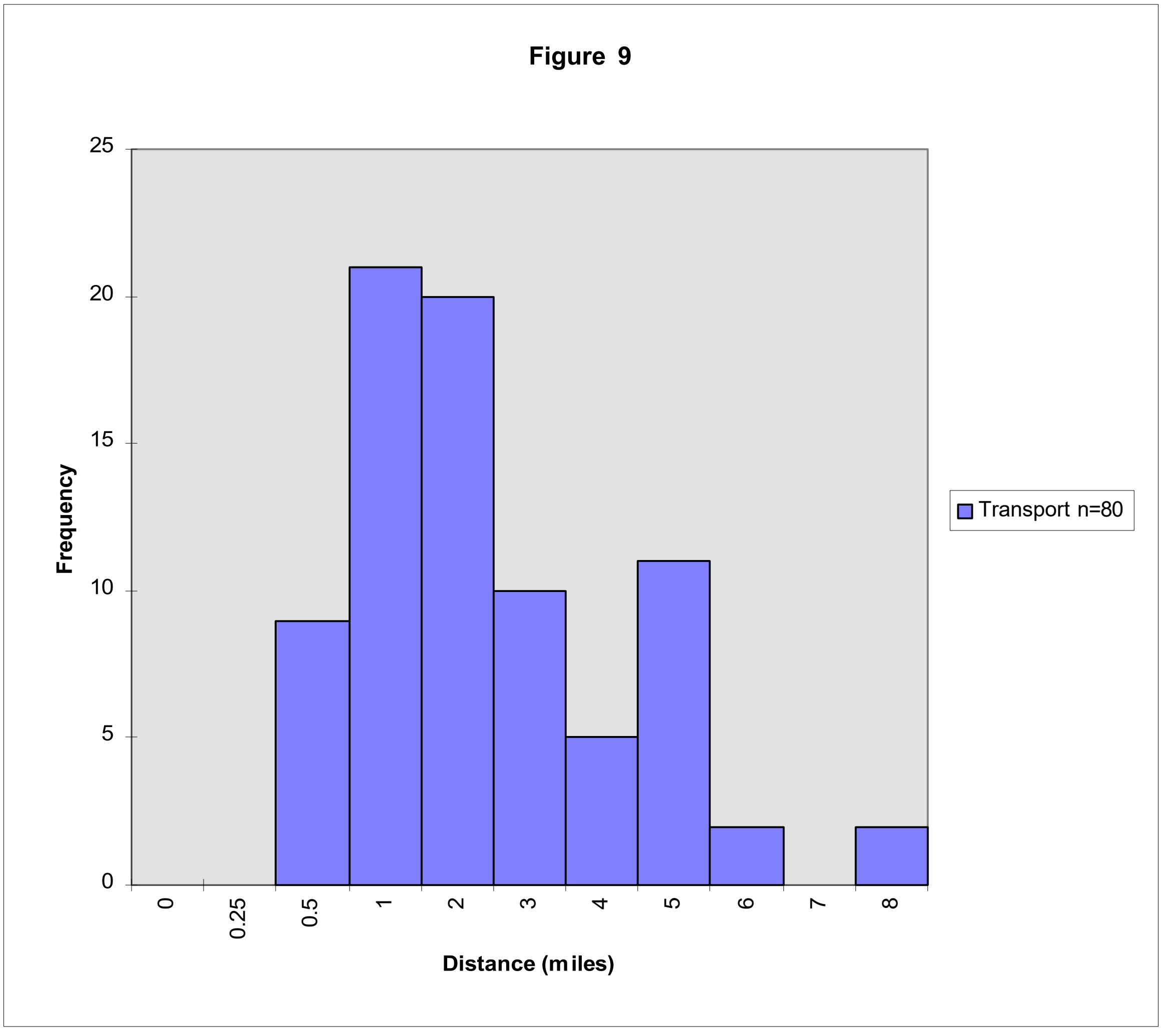

Figure 9. (n = 80) Distribution of FAA/DAC pilot estimates for expected distance needed to perform "a normal corrective action" to avoid Transport Category aircraft traffic, during daytime VFR conditions.

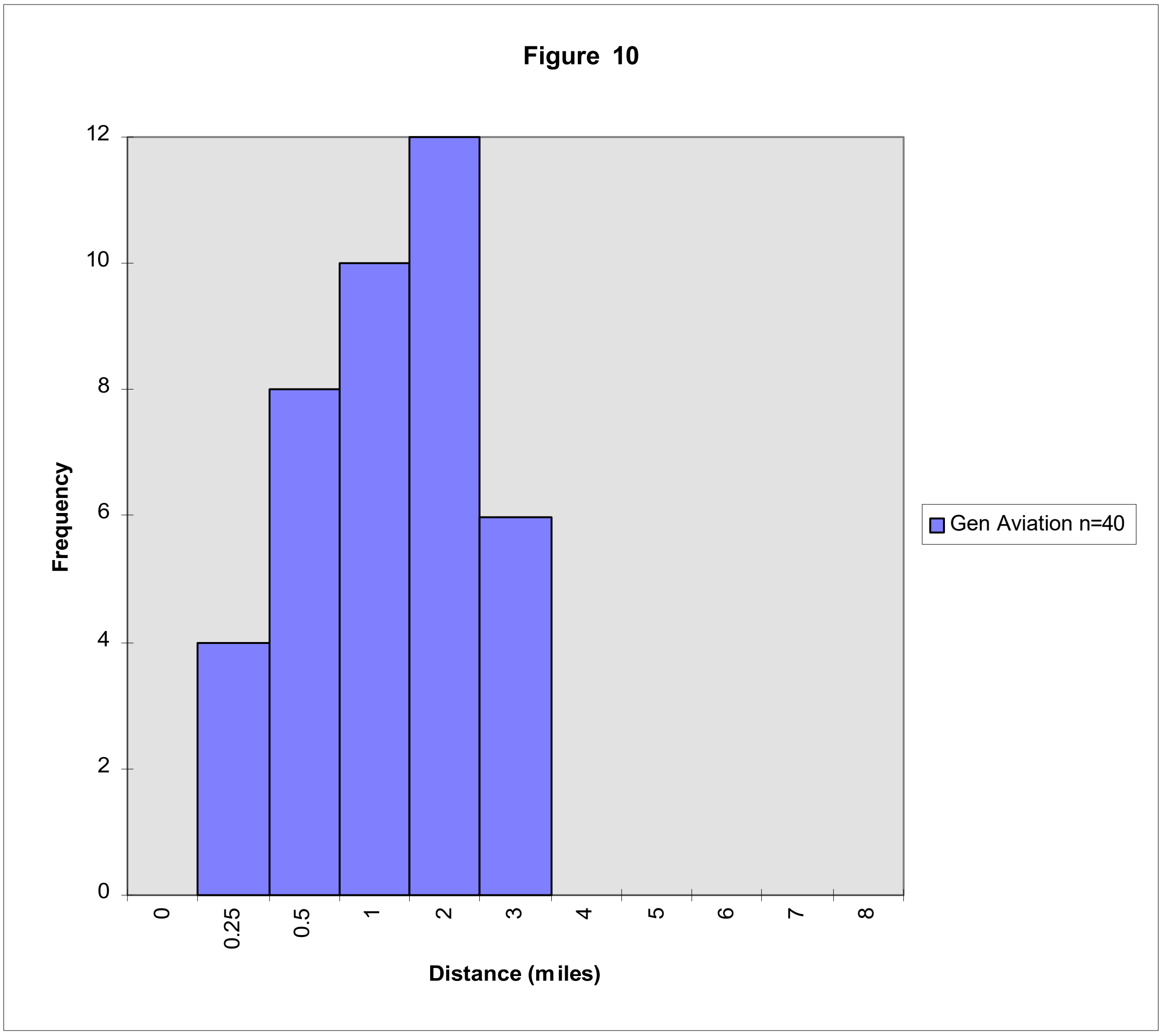

Figure 10. (n = 40) Distribution of FAA/DAC pilot estimates for expected distance needed to perform "a normal corrective action" to avoid General Aviation Category aircraft traffic, during daytime VFR conditions.

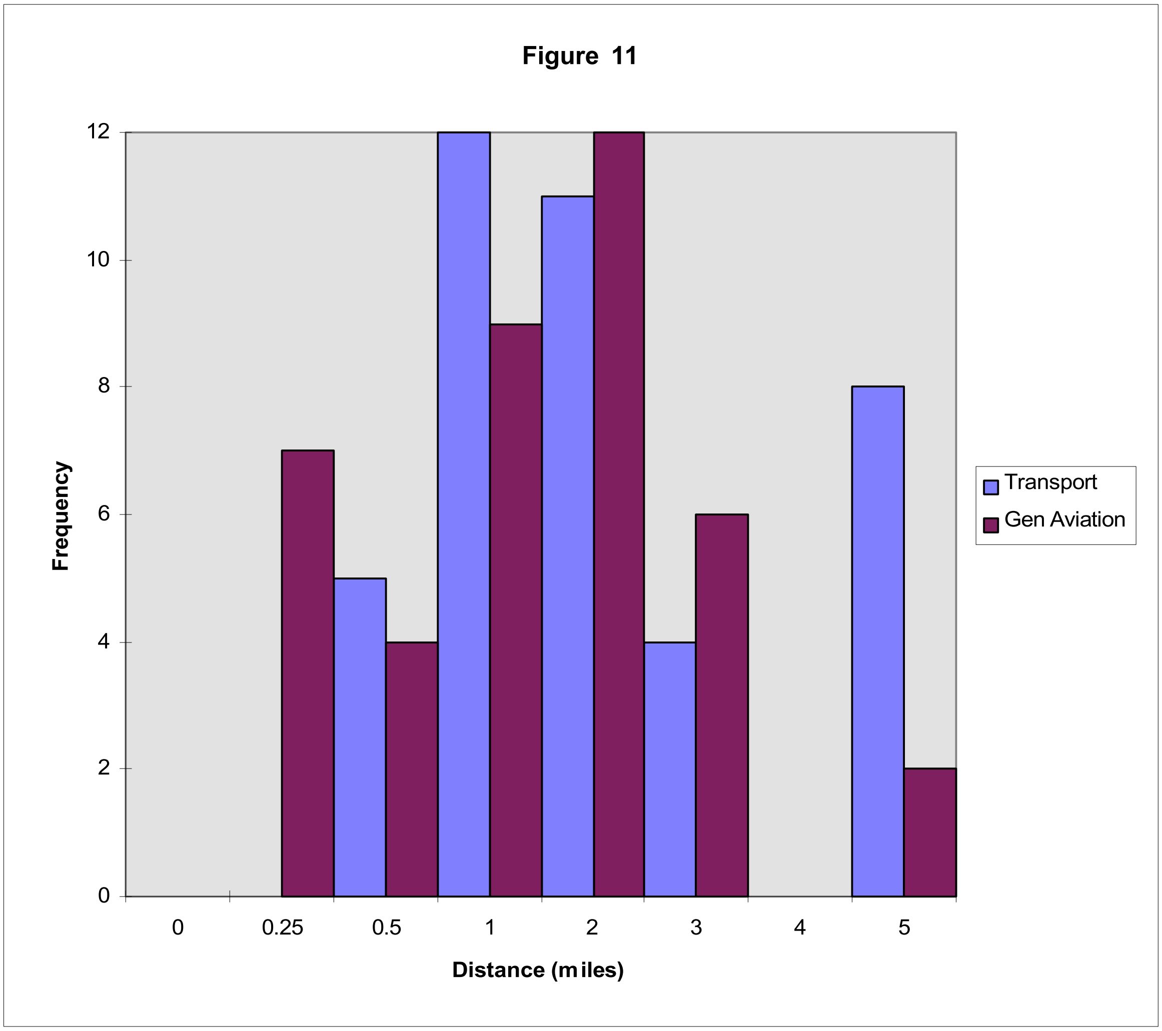

Figure 11. (n = 40) Distribution of FAA/DAC pilot estimates for expected distance needed to perform "a normal corrective action" to avoid Transport and General Aviation Category aircraft traffic at night.

	Daytime - Acquire Target		Nighttime - Acquire Target	
	Range	Highest Frequency / Comments	Range	Highest Frequency / Comments
747-400				
Perpendicular	10 - 40m	20 miles	10 - 40m	40 miles
Towards	6 - 15m	10 miles	5 - 40m	20 and 40 miles
MD-80				
Perpendicular	7 - 20m	15 miles	6 - 40m	20, 30 and 40 miles
Towards	4 - 10m	5 and 10 miles	5 - 40m	20 and 40 miles
Cessna 172				
Perpendicular	2 - 10m		2 - 25m	10 miles
Towards	2 - 7m	57% responded acquire at 2 miles	0.5 - 25m	10 miles
	Daytime - Identify Target		**Nighttime - Identify Target**	
	Range	Highest Frequency / Comments	Range	Highest Frequency / Comments
747-400				
Perpendicular	4 - 15m		0 - 8m	43% responded cannot identify
Towards	3 - 10m		0 - 5m	57% responded cannot identify
MD-80				
Perpendicular	2 - 10m		0 - 6m	43% responded cannot identify
Towards	0 - 7m	50% responded acquire at 2 miles	0 - 5m	57% responded cannot identify
Cessna 172				
Perpendicular	0 - 5m	43% responded id at 1 mile	0 - 4m	43% responded cannot identify
Towards	0.5 - 6m	71% responded id at 0.5 to 1 mile	0 - 5m	71% responded cannot identify

Table 1. Air National Guard F-16 pilot estimates (n=40) for visual acquisition and identification of a Northwest 747-400, an American MD-80, and a white Cessna 172, during daytime (noon) and nighttime VFR conditions, given that the airborne traffic at 10k ft is approaching perpendicular and directly towards respondent's flight path. For each condition, the minimumand maximum pilot estimates (in miles) are provided along with the highest frequency response.