The Usefulness of the Proximate Status Indication as Represented by Symbol Fill on Cockpit Displays of Traffic Information

DOT/FAA/TC-13/24

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13. ABSTRACT (Maximum 200 words)

Traffic Alert and Collision Avoidance Systems (TCAS) displays depict traffic advisories, resolution advisories, and information on other aircraft. Symbols for other aircraft include the proximate status indication where the symbols of "proximate" (close) aircraft are filled and the symbols of "non-proximate" (more distant) aircraft are not filled. This web-based study examined the value of the proximate status indication as represented by symbol fill to assess implications for Cockpit Displays of Traffic Information (CDTIs), and found no advantage for it, only a disadvantage.

Pilots viewed videos of traffic displays. Analysis of the data failed to show a benefit of the proximate status indication for estimating threat and potential for visual acquisition of traffic. Analysis did find a decrement in performance for identifying the greatest traffic threat, when the proximate status indication was depicted. In contrast to their performance, most pilots say the proximate status indication is useful. However, results indicate that pilots overemphasize proximity and underemphasize closing speeds when assessing threat levels. This bias may account for the pilot preference for displaying proximate status. Results of this study are intended to be of use to the Federal Aviation Administration in developing guidance material for CDTIs.

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Preface

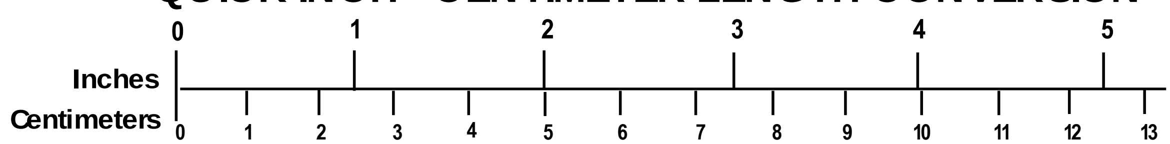
This technical report was prepared by the Center for Human Factors Research and System Applications at the John A. Volpe National Transportation Systems Center (Volpe Center). This research was completed with funding from the Federal Aviation Administration (FAA) Human Factors Division (ANG-C1) in support of the Aircraft Certification Service Avionics Branch (AIR-130) and the Technical Programs and Continued Airworthiness Branch (AIR-120).

Thanks to the FAA program managers Thomas McCloy and Colleen M. Donovan and the FAA technical sponsors Bill Kaliardos and Cathy Swider for their assistance. Wes Olson of the Massachusetts Institute of Technology Lincoln Laboratory also provided valuable insights and feedback on the study. Particular thanks go to Matt Isaacs from the Volpe Center for creating the web interface used for data collection and to Andrew Kendra and Alan Yost for creating the traffic video scenarios using their CDTI simulator software. Thanks also to all the pilots who participated in the study and to the many organizations and individuals who contributed.

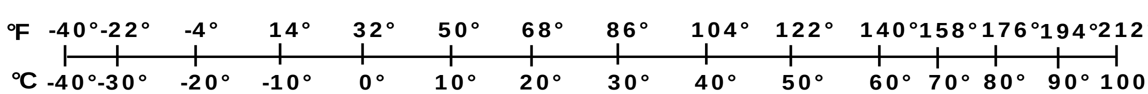
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH (APPROXIMATE)**	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA (APPROXIMATE)**	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha] = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT (APPROXIMATE)**	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg)
			= 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME (APPROXIMATE)**	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE (EXACT)**	
((x-32)(5/9)) °F	= y °C	((9/5) y + 32) °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERS



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price [2.50 SD Catalog No. C13 10286 Updated 6/17/98

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Executive Summary

This study assessed the usefulness of the proximate status indication, as represented by symbol fill, on a traffic display. On Traffic Alert and Collision Avoidance System (TCAS), a filled diamond-shape symbol designates a proximate (close) aircraft and an unfilled diamond-shaped symbol designates a non-proximate (more distant) aircraft. Traffic proximity is distinct from the alert state, which is computed based primarily on time until the closest point of approach, rather than closeness. Traffic that are farther away could be a higher threat than closer traffic at a given point in time, as defined in TCAS, if the farther traffic is closing at a high relative speed. Questions have been raised about whether the TCAS proximate status indication should also be displayed on newer Cockpit Displays of Traffic Information (CDTIs).

This study tested the usefulness of the proximate status indication for assessing:

- *Threat*, that is, does the proximate status indication help pilots assess the chance that traffic will produce a traffic advisory (TA)?
- *Potential for visual acquisition*, that is, does the proximate status indication help pilots decide if traffic is close enough to be visually acquired?

Both of these assessments are important for guiding the pilot's visual search for traffic.

In the study, over 100 corporate and airline pilots viewed videos of traffic scenarios depicted on a traffic display. This study found no advantage for the proximate status indication as represented by symbol fill, only a disadvantage. The study found that the proximate status indication did not help pilots assess the threat or potential for visual acquisition of traffic. Instead, pilot accuracy for assessing the comparative threat between pairs of aircraft was worse with the proximate status indication than without.

The study results revealed that most pilots regard the proximate status indication, as represented by symbol fill, to be useful. The gap between pilot opinion and pilot performance is likely due to pilots on average over-weighing the closeness of traffic when judging traffic threat. This study found evidence that pilots weigh closeness more than other traffic characteristics, such as apparent closing speed, regardless of whether or not a display includes the proximate status indication. Pilots may value the proximate status indication because they regard closeness to be the overriding factor in threat estimations. This bias may account for the pilot preference for displaying the proximate status indication.

Results of this study are intended to be of use to the Federal Aviation Administration in developing guidance material for CDTIs.

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Acronyms

ADS-B	Automatic Dependent Surveillance Broadcast
AIS	Aeronautical Information Services
ALPA	Air Line Pilots Association
ANOVA	Analysis of Variance
ASAS	Aircraft Surveillance Applications Systems
ATC	Air Traffic Control
CPA	Closest Point of Approach
CDTI	Cockpit Display of Traffic Information
DC	District of Columbia
DOT	Department of Transportation
FAA	Federal Aviation Administration
FPM	Feet per minute
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
KJFK	John F. Kennedy International Airport
LA	Los Angeles
MA	Massachusetts
MET	Meteorological
MOPS	Minimum Operational Performance Standards
NBAA	National Business Aviation Association
NM	Nautical mile
NY	New York
OMB	Office of Management and Budget
OTW	Out the window
RA	Resolution Advisory
RJ	Regional Jet
SPR	Safety and Performance Requirements
SURF-IA	Surface Indications and Alerts
TA	Traffic Advisory
TCAS	Traffic Collision Avoidance System
TRACON	Terminal Radar Approach Control
TSO	Technical Standard Order

VA	Virginia
VFR	Visual Flight Rules
VNTSC	Volpe National Transportation Systems Center

1. BACKGROUND AND MOTIVATION

As flight deck displays make more and more information available to the pilot, one challenge is to maintain compatibility with older familiar systems while still maximizing the benefits of the new technology. This is the case for traffic display symbology, which was originally developed for the Traffic Collision Avoidance System (TCAS), an air-to air surveillance system. Many airline and corporate pilots have experience with the TCAS. TCAS is therefore the conceptual basis for design of newer flight deck traffic systems known as Cockpit Displays of Traffic Information (CDTIs). In the future, TCAS traffic displays (which are based on onboard air-to-air surveillance data) may be integrated with CDTIs.

During the development of the recently published RTCA DO-317A, *Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications System (ASAS)* (RTCA, 2011), the standards working group discussed whether CDTI symbols would be required to match TCAS traffic symbols in certain ways. The group determined that it is desirable to retain aspects of TCAS symbology and coding conventions in the CDTI symbols because of extensive pilot experience with TCAS.

However, replicating all TCAS symbology in CDTIs can present problems. ADS-B gives CDTIs more information about traffic than is available to TCAS. There is a limited supply of visual features that symbology can use to encode information before pilots start to become confused (Chandra, Zuschlag, Helleberg, and Estes, 2009; Zuschlag, Chandra, Helleberg, and Estes, 2010). Consequently, it is difficult to create a symbol set for a display that graphically encodes all information found in both CDTI and TCAS displays. Some manufacturers are proposing to change the TCAS coding conventions on CDTI that have been used in TCAS for years.

One proposed option to combine TCAS and CDTI symbology is encode only information that is useful to the pilot. The focus of this study is to examine the usefulness of the proximate status indication as represented by symbol fill.

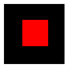
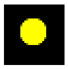
1.1. TCAS Symbology and the Proximate Status Indication

TCAS includes a plan view traffic display that graphically depicts the lateral position of traffic around the ownship position, with a text tag to indicate altitude relative to the ownship. The tag also shows an arrow (up or down) or no arrow to indicate categorically whether traffic is a climbing, descending, or holding altitude.

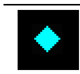
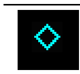
The currently approved TCAS traffic display has symbols for resolution advisories (RAs), traffic advisories (TAs), proximate, non-proximate, as listed in Table 1. These four symbols are divided into two categories: (1) threat symbology, and (2) non-threat symbology.

Table 1. Symbol set of the currently approved TCAS traffic display.

Threat Symbology

Symbol	**Name**	**Alert State**	**Criteria**[1]	
			Time to Closest Point of Approach	*Projected* Separation
	RA	Resolution Advisory	15 to 35 seconds to closest point of approach	Low
	TA	Traffic Advisory	Approximately 10 seconds prior to RA criteria	Low

Non-Threat Symbology

Symbol	**Name**	**Alert State**	**Criteria**
			Current Lateral and Vertical Separation
	Proximate	Non-alert	Closer than 6 nm laterally and 1200 ft vertically
	Non-proximate	Non-alert	Farther than 6 nm laterally or 1200 ft vertically

The main difference between threat and non-threat symbology lies in the use of time and current versus projected separation. Threat symbology criteria involve time to closest point of approach and *projected* separation at closest point of approach. In contrast, non-threat symbology criteria involve solely *current* horizontal and vertical separation; time is not included in these criteria.

In the threat symbology, traffic associated with resolution advisories (RAs) are red squares and those associated with traffic advisories (TAs) are yellow circles. In the non-threat symbology, the *proximate status indication* is symbol fill, where proximate aircraft appear as filled diamonds and non-proximate aircraft appear as unfilled (outlined) diamonds. A proximate aircraft is defined as one currently within 6 nautical miles laterally and 1200 feet relative altitude vertically, and a non-proximate aircraft is defined as one currently outside these parameters.

Thus, alert state and proximity are distinct dimensions in TCAS (Federal Aviation Administration, 2000; RTCA, 2008). TCAS generally determines alert state by the time until the traffic's closest point of approach to ownship, and the projected miss distance between aircraft and ownship at the closest point of approach. For most situations, proximity (i.e., *current* closeness) of the traffic enters into TCAS threat algorithm indirectly, in that time until closest point of approach depends not only on closeness but also on the relative speed of closure.

Farther traffic could be a higher threat at a given point in time, as defined in TCAS, than closer traffic. For example, assume ownship to be cruising at 30,000 feet and 400 knots true airspeed as illustrated in Figure 1.

[1] These are simplified general criteria for threat symbology. Exact variables and values defining each alert state depend on various adjustments and conditions (e.g., ownship altitude). See Federal Aviation Administration (2000), Introduction to TCAS II Version 7.1; and RTCA (2008), Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II), DO-185B.

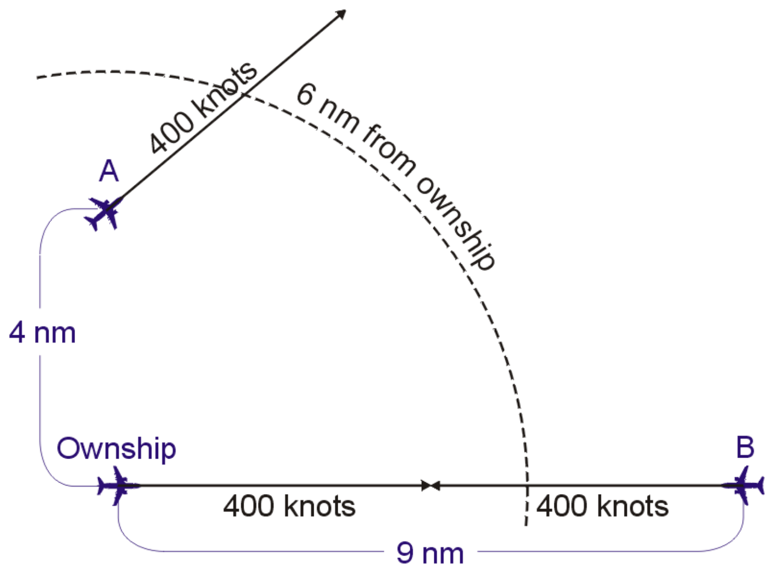


Figure 1. Example of more distant traffic constituting a greater threat.

Aircraft A, also at 30,000 feet and 400 knots, is four miles directly abeam ownship and has a relative trajectory that is diverging from the ownship. Such traffic qualifies as proximate, being currently within six miles and 1200 feet. However, it does not represent a substantial threat and indeed would not trigger a TA or RA if both aircraft maintain their speeds and tracks. Contrast this to Aircraft B, tracking directly towards the ownship at 30,000 feet and 400 knots from nine nautical miles directly ahead. The Aircraft B is non-proximate, being currently over six miles away. However, even though Aircraft B is more than twice as far from the ownship as Aircraft A, it represents a substantially greater threat, potentially colliding with the ownship in only 40 seconds; indeed, Aircraft B would have triggered a TA when approximately 11 miles away.

1.2. Potential Functions for the Proximate Status Indication

CDTI manufacturers are seeking the flexibility in the standards to use symbol fill for purposes other than as a proximate status indication. This raises the question as to how useful the proximate status indication is. In assessing the usefulness of the proximate status indication, one may ask, "usefulness for doing what?" The TCAS standards RTCA DO-185B *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II)* (RTCA, 2008), invoked by TSO-C119c (FAA, 2009), describe the intended function of the entire traffic display and they require displays to show proximate traffic during alerts. There is no requirement to show non-proximate traffic during an alert because this traffic is likely to be out of visual range, but many systems do display them for general traffic awareness. Whether these symbols have the proximate status indication is a separate matter

Whatever the original intent for the proximate status indication, pilots may have developed uses for the proximate status indication that affect the operational use of TCAS. However, it appears that no previous research has investigated what these uses might be.

With no documented intended function and no research on the use of the proximate status indication, a possible use was identified through informal conversations with approximately 20 pilots. From these conversations, it is hypothesized that the proximate status indication may be useful for estimating the threat level of traffic that is not in an alert status. More specifically, it is hypothesized that the proximate status indication may assist pilots to focus their visual search in advance on traffic that are likely to produce a traffic advisory (TA). Regarding filled symbols as potential threats is not entirely consistent with the TCAS alert algorithm, but it is nonetheless understandable. While the criteria for a TA depends primarily on time until the closest point of approach (FAA, 2000; RTCA, 2008) rather than proximity or distance to traffic, closer traffic are in general more likely to become a TA than more distant traffic.

Another possibility is that the proximate status indication aids pilots in deciding *whether* to attempt visual acquisition. That is, does the proximate status indication help pilots decide if traffic is close enough to be visually acquired? Pilots can make better use of their resources if they do not waste time attempting to visually acquire traffic that is at a distance or visual angle that renders it undetectable out the window. Traffic more than 6 nm away is unlikely to be visible (Andrews, 1991), so the proximate status indication might cue pilots to attempt visual search for traffic that they know are closer to them. They may decide not to search for non-proximate traffic, assuming they are either too distant laterally, or, if they are very close laterally, they may be obstructed by the fuselage structure.

This study tests the hypothesis that the proximate status indication is useful for assessing threats and potential for visual acquisition. This hypothesis is consistent with the intended function of the TCAS traffic display as a whole (RTCA, 2008). The study also investigates other uses of the proximate status indication. The research objectives and experimental measures for this project are outlined in the following section.

1.3. Research Objectives

This study addresses the research question:

> What is the usefulness of the proximate status indication on traffic display?

To assess the usefulness of the proximate status indication on traffic display, this study tests whether the proximate status indication helps or hurts pilot performance. Specifically this research:

- Experimentally measured the degree to which the proximate status indication aids pilot assessment of the threat and potential for visual acquisition of traffic.
- Experimentally measured the degree to which the proximate status indication potentially interferes with (in contrast to aiding) the pilot assessment of traffic threat.
- Gathered pilots' subjective opinions based on their operational experiences with the proximate status indication; what it is used for, and how it may aid or interfere with traffic-related activities.
- Assessed pilot knowledge and understanding of the proximate status indication.

Results of this study are intended to feed into an update of RTCA DO-317A (RTCA, 2011), which is intended to be invoked by of use to the Federal Aviation Administration (FAA)'s updated Technical Standard Order for CDTIs (TSO-C-195a, FAA, 2012). Because TCAS does not contend with tight competition among information for symbol features, the results are not necessarily relevant for TCAS-only displays.

2. METHOD

The study was completed with web-based materials for efficient access to and large sample of pilots. Appendix A provides the questions and materials used in the web-based study.

2.1. Participants

Advertisements were placed in newsletters for the Air Line Pilots Association (ALPA) and the National Business Aviation Association (NBAA) to recruit airline and corporate pilots based in the United States. The announcements asked pilots with TCAS experience to visit a website in order to complete the study.

The participants answered questions about their background on one of the first pages. The site allowed only participants who indicated they were currently licensed pilots with TCAS experience to complete the study, as the results were intended to generalize to pilots with TCAS experience.

One hundred and thirty-six participants participated in the study, of whom 101 completed all of the study, yielding a 31% attrition rate, which is comparable to a previous CDTI web study (Chandra, et al, 2009).

Table 2 shows a breakdown of the participants by reported type of operations they conduct, experience with TCAS, and average flight hours. In general, pilots were highly experienced. Most had air transport experience and many had corporate experience. All participants reported some TCAS experience, typically with TCAS II.

Table 2. Participant characteristics.

Operation	Average Flight Hours	**Experience** Number of Pilots		**Total** Number of Pilots
		TCAS I	**TCAS II**	
Air Transport	8793	3	69	70
Corporate	9429	9	45	47
Military	12675	1	16	16
Private Only	630	3	0	3
Overall	**8837**	**12**	**96**	**101**

2.2. Procedure Overview

The study was divided into four tasks (see Table 3) that the pilots completed sequentially. Table 3 also provides the number of participants completing each task. All collected data for each task was used regardless of whether a pilot completed subsequent tasks.

Figure 2 illustrates the procedure for each participant. All participants completed the tasks in the order given in Table 3 and shown in Figure 2. The task order was intended to minimize the degree that exposure to an earlier task would interfere with the interpretation of the results from a later task. For example, the greatest threat task (Task 2) presented pilots with counter-intuitive traffic scenarios. Therefore, the greatest threat task was after the traffic rating task so that exposure to these counter-intuitive scenarios would not affect response to the scenarios in the traffic rating task. The knowledge of TCAS symbology task (Task 4) included potential definitions for the proximate status indication. This task was last because exposure to such definitions may encourage pilots to think about the proximate status indication differently than they normally do operationally.

Table 3. Tasks and research objectives.

	Task	Objective	Pilot's Activity	Number of Pilots
1	Traffic Rating	Measure the degree to which the proximate status indication aids pilot assessment of threat and potential for visual acquisition of traffic.	Provided ratings of the threat and the potential for visual acquisition of traffic in videos.	110
2	Greatest Threat	Measure the degree to which the proximate status indication potentially interferes with (in contrast to aiding) the pilot assessment of traffic threat.	Identified the traffic that represented the greatest threat in videos	102
3	Operational Experience	Gather pilots' subjective opinions based on their operational experiences with the proximate status indication; what it is used for, and how it may aid or interfere with traffic-related activities	Answered forced-choice and open-ended questions about the operation use of the proximate status indication.	100
4	Knowledge of TCAS Symbology	Assess pilot knowledge and understanding of the proximate status indication.	Answered true-false factual questions on the definitions of TCAS symbols.	101

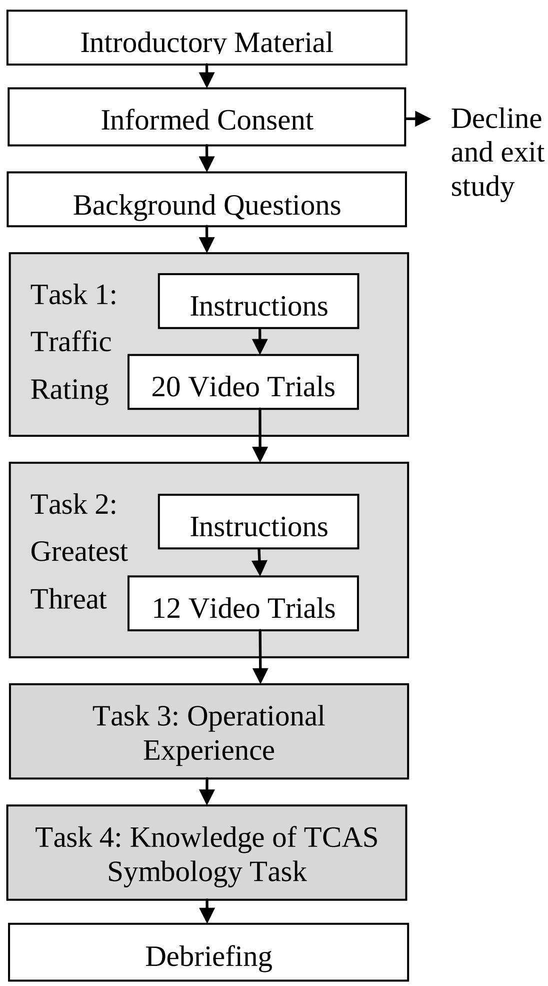


Figure 2. Procedure for each participant.

The average total time for pilots to complete all forms and tasks was 29 minutes.

2.3. Task 1: Traffic Rating

The purpose of the traffic rating task (Task 1) was to measure the degree to which the proximate status indication aids pilot assessment of the threat and potential for visual acquisition of traffic. Specifically, the traffic rating task measured pilots' ability to use the proximate status indication to assess:

- *Threat*, that is, does the proximate status indication help pilots assess the chance that an aircraft will produce a traffic advisory (TA)?
- *Potential for visual acquisition*, that is, does the proximate status indication help pilots decide if an aircraft is close enough to be visually acquired?

This was accomplished by presenting 20 trials in random order, each with a 15-second video where the threat and potential for visual acquisition of traffic were realistically correlated with the proximate status of the aircraft. Figure 3 shows a screen capture from an example video.

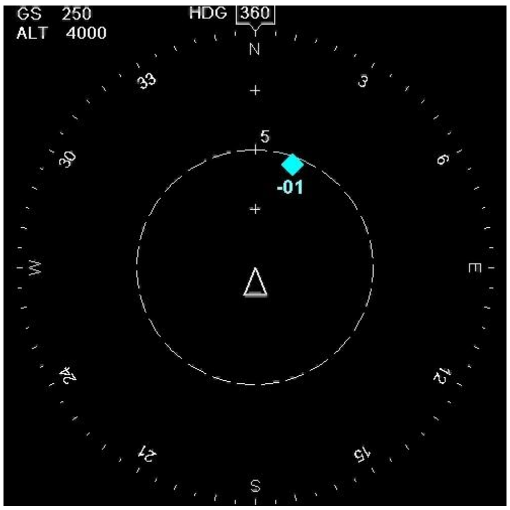


Figure 3. Screen shot from a traffic rating task (Task 1) video.

When the video ended, all information in the display was removed except for the symbol of one experimenter-chosen aircraft. In all cases, the chosen aircraft was generally converging laterally and vertically on ownship. Pilots subjectively rated chosen aircraft for threat and potential for visual acquisition on forced-choice scales from 0% to 100% in 10% increments indicating the chance "of this traffic becoming a TA in the next 60 seconds" and "you could quickly visually acquire this traffic with visibility unrestricted."

To assist pilots in making ratings for potential visual acquisition, instructions prior to the videos told pilots that "you are looking for a 50-seat regional jet aircraft in daytime with visibility unrestricted conditions."

The chosen aircraft varied in range and relative speed across the 20 trials. The net effect was that time to closest point of approach, which is the parameter that TCAS primarily uses to assess threat, varied across trials. The variability in range also represents variation in the actual potential for visual acquisition of the traffic, with more distant aircraft being harder to see than closer aircraft.

The ranges and speeds were chosen to be similar to that encountered operationally, based on an analysis of radar data from the New York terminal area. Details of the analysis are in Appendix

B. The correlation between the proximate status indication and time to closest point of approach was a little higher in these test scenarios than in the radar data so the proximate status indication was a slightly better indication of threat in these videos than in reality. All aircraft also varied across the videos in their angles relative to the ownship and whether or not they were changing altitude. All aircraft held straight trajectories. Also, aircraft did not change from proximate to non-proximate status (or vice versa) during a single trial (15-second video). Appendix C details the traffic behavior and compares it to real traffic.

The videos were refined through multiple iterations, reviews, and testing to achieve a reasonable level of difficulty and realism.

2.3.1. *Experimental Conditions*

Each pilot was randomly assigned to one of four different conditions created by crossing the two independent variables, proximate status indication and traffic density.

Proximate status indication had two levels:

- *With indication*, where the display had filled symbols for proximate (close) traffic and unfilled symbols for non-proximate (more distant) traffic, as seen on TCAS displays.
- *Without indication*, where the display had only unfilled symbols (i.e., the display did not have any symbology or coding features or functions to distinguish traffic that are proximate or close by vs. those that were not). Thus, in this condition the symbols for proximate traffic were identical to the symbols for non-proximate traffic).

Instructions provided before the task listed all symbols the display would show and warned pilots that "the display does not have all the features of TCAS," so pilots would not be surprised or concerned by displays without the proximate status indication (i.e., displays without filled symbols).

Traffic density also had two levels:

- *Low density*, with a single aircraft within 10 nm that, of course, became the chosen aircraft.
- *High density*, with five aircraft within 10 nm, which corresponds to the 80th percentile from the radar data from the New York terminal area.

The traffic density variable allowed comparisons between cases where pilots can devote all their attention to a single aircraft and cases where pilots must divide their attention. In the latter situation, pilots may need to rely more on information that can be extracted quickly from a traffic display symbol, for example, the information represented by symbol fill. Appendix C details the behavior of the distracter traffic.

2.3.2. *Performance Measures for Traffic Rating Task (Task 1)*

Performance measures for the traffic rating task (Task 1) were derived from the pilot ratings of the threat and the potential for visual acquisition of traffic in videos. The performance measures were:

- The consistency of pilot's ratings with the actual level of threat and potential for visual acquisition. This was measured by R^2, defined below.
- The weight pilots placed on each component of threat and potential for visual acquisition in their ratings. This was measured by *B* coefficients, defined below.
- The ratings of threat and potential for visual acquisition themselves.

To measure the degree to which the proximate status indication aids the pilot's assessment of the threat and potential for visual acquisition of traffic, a mathematical procedure measured the degree each pilot's subjective ratings were consistent with the actual threat and potential for visual acquisition. The actual threat was defined by the TCAS alert algorithm. The TCAS alert algorithm was used to define actual threat because:

- The study concerned the use of the proximate status indication specifically for anticipating TAs.
- The definition of a TCAS TA is the result of extensive work by the expert aviation community, and has wide acceptance.
- The definition of a TCAS TA has proven to perform excellently in actual operations.

For the kinds of encounters presented in the videos, TCAS determines threat by the time to closest point of approach and miss distance between traffic and ownship at closest point of approach. Proximity (i.e., closeness) of the traffic enters into the threat algorithm indirectly in that time until closest point of approach depends on closeness and relative speed of closure.

To measure how much the subjective ratings of threat correlated with actual threat, a least-square multiple regression was performed on each the pilot's 20 ratings of threat (one rating from each of 20 trials) using the model shown in Equation (1).

$$T = B_0 + B_t t + B_v v + B_h h \qquad (1)$$

Where:

T = pilot's subjective rating of threat.

t = true time until closest point of approach.

v = true vertical miss distance at the closest point of approach.

h = true horizontal miss distance at the closest point of approach.

B_i = Regression weights.

The result is a number for each pilot, R^2, which is a unit-less coefficient between 0 and 1 that represents the consistency of each pilot's ratings with actual threat. That is, R^2 indicates the tendency a particular pilot consistently rates traffic with higher time to closest point of approach and greater miss distances as less threatening than traffic with lower time to closest point of approach and smaller miss distances [2].

R^2 is high if a pilot's ratings of threat vary systematically with time to closest approach and/or miss distance. This would imply the pilot can effectively assess the actual threat of traffic using the traffic display. An R^2 of 1.0 would indicate that pilots can perfectly estimate relative time to closest point of approach and miss distances from the videos. An R^2 of 0 indicates no relation between actual threat and a pilot's 20 ratings. Rather, the pilot's ratings vary randomly with

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[2] This use of multiple regression to define a dependent measure for each pilot is in contrast to the more common use of regression in inferential statistical analysis to determine the relationship between a dependent and independent variables. Here, one regression per subject produced an R^2 for each subject (i.e., in this case, there were 110 regressions resulting in 110 R^2s). In inferential statistical analysis, a single regression is performed for all subjects combined, resulting in a single R^2.

actual threat. This would suggest either (a) the pilot does not regard threat to be related to traffic closeness, relative speed, time to closest point of approach, or miss distances, or (b) the pilot is unable to reliably extract from the display the closeness, relative speed, time to closest point of approach, or miss distances of traffic.

For these particular videos, if a pilot adopted a simple strategy of regarding all proximate traffic as threatening and all non-proximate traffic as non-threatening, ignoring relative speed, time to closest point of approach, and miss distances, then the R^2 would be 0.18 (see Appendix C.1).

Ratings of potential for visual acquisition were evaluated through a similar process, using the model in Equation (2).

$$V = B_0 + B_r r + B_g g + B_{rg} rg \qquad (2)$$

Where:

V = pilot's subjective rating of the potential for visual acquisition.

r = range from ownship to the aircraft.

g = presence of ground clutter if the pilot were to search out the window, equal to

1 if the aircraft has a negative relative altitude (is below the horizon).

0 otherwise.

The ground (B_g) and range-by-ground (B_{rg}) coefficients accounted for the degree pilots include anticipated ground clutter effects in their assessments of the traffic potential for visual acquisition. The ground coefficient accounted for the potential of ground clutter to have a constant effect on potential for visual acquisition irrespective of range, while the range-by-ground-interaction coefficient accounted for the potential for visual acquisition falling off at different rates with increasing range depending on whether or not the traffic appeared over ground clutter.

If the proximate status indication helps pilots quickly estimate distances, then the ratings of threat and potential for visual acquisition of pilots with the proximate status indication should be more consistent with actual threat and potential for visual acquisition than the ratings of pilots without the proximate status indication. That is, the ratings of each pilot on average, should exhibit a stronger tendency to increase as actual threat and potential for visual acquisition increases.

Performance was collectively indicated by the weights (the *B* coefficients) for each pilot's regression equation. These can be used to discriminate certain cases where a pilot is consistent, but not accurate. For example, with the rating of threat, a pilot can completely ignore time to closest point of approach and simply rate traffic based only on miss distance. They can be consistent with this, resulting in a high R^2, but that is not a very complete assessment of threat.

The standardized *B*s represents the weight a pilot puts on each component of threat. For example, maybe pilots with the proximate status indication attend more to miss distances than pilots without because it is easier for them to estimate range and therefore time to closest point of approach. This would appear as a significant difference between the standardized *B*s for the miss distances for pilots with and without the indication.

For this purpose, the regressions using Equation (1) were supplemented by regressions with time to closest point of approach broken down into its components: relative speed and range using Equation (3).

$$T = B_0 + B_s s + B_t r + B_v v + B_h h \quad (3)$$

Where:

T = pilot's subjective rating of threat.

s = relative closing speed of the aircraft.

r = range to aircraft at end of the video.

v = true vertical miss distance at the point of closest approach.

h = the true horizontal miss distance at the point of closest approach.

B_i = regression weights.

Time is in fact range divided by speed, not the weighted sum of range and speed as shown in Equation (3). However, with this particular experimental setup, time to closest point of approach is accurately estimated by a weighted sum of standardized range and speed values (correlation $R = 0.90$). A weighted sum of the components, rather than another function of the components, is necessary to allow the analysis to indicate the emphasis pilots put on time, speed, and range in threat assessments. If pilots consider range and speed equally, then they are in effect looking at time to closest approach, and assess threat in the same way that TCAS does. If pilots use range more than speed, then they are using range in addition to time, and vice versa if they use speed more than range. It is possible that for assessing threat the proximate status indication makes range seem more important to pilots than it is in TCAS.

Another set of measures, in addition to the consistency of pilot ratings with actual threat and potential for visual acquisition, were the ratings of threat and potential for visual acquisition themselves. The average ratings were compared on three independent variables. Two variables were the same between-subjects experimental conditions used to analyze consistency with objective reality: proximate status indication (two levels, with indication and without indication) and traffic density (also two levels, low density and high density). The third variable, a within-subjects variable, was the proximity of the aircraft, where for each pilot, half of the time the aircraft was proximate (i.e., within 6 nm lateral and 1200 ft vertical of the ownship) and half the time it was non-proximate (i.e., outside these boundaries).

Comparing mean ratings across these conditions assessed the impact of symbol fill on ratings of threat and potential for visual acquisition. For example, if proximate traffic are seen on average as more threatening when filled than when not, then it suggests fill accentuates perceived threat beyond that induced by the perceived range and velocity of the traffic.

2.4. Task 2: Greatest Threat

The purpose of the greatest threat task (Task 2) was to measure the degree to which the proximate status indication potentially interferes with, in contrast to aiding, the pilot assessment of traffic threat. This is in contrast to the traffic rating task (Task 1, discussed in Section 2.3), which was designed to measure the degree to which the proximate status indication aids pilot assessment of the threat and potential for visual acquisition of traffic.

While traffic proximity is correlated with actual threat, it is not a perfect correlation; if there is sufficient difference in relative closing speed, farther traffic could be a higher threat at a given point in time, as defined in TCAS, than closer traffic. The greatest threat task (Task 2) presented pilots with cases where proximate traffic was more threatening than non-proximate traffic and vice versa in order to determine if pilots over-rely on the proximate status indication.

Pilots were shown 12 15-second videos of traffic displays in random order. In every video there was always one proximate aircraft converging on the ownship, and one non-proximate aircraft converging on the ownship. At the end of each video, the context of the display was removed so that only the traffic and a letter next to each aircraft were visible to the participant. The participant then selected (by letter) the aircraft they felt was most likely to produce a TA. The dependent variable for this task was whether participants accurately selected the aircraft that actually had the greatest threat as determined by the TCAS alert algorithm.

The greatest threat aircraft, whether it was proximate or non-proximate, had a time to closest point of approach of 49 seconds at the end of each video, and a 0 lateral and vertical miss distance at closest point of approach. The lesser threat aircraft had characteristics of one of the rows in Table 4 in each video. That is, the lesser threat aircraft varied in how they were a lesser threat, either because of a longer time to closest point of approach or because they were on a track that would miss the ownship laterally or vertically.

Table 4. Lesser threat aircraft characteristics.

Aircraft	Time to Closest Point of Approach	Lateral Miss	Vertical Miss
1	196 sec	0 nm	0 ft
2	49 sec	2 nm	0 ft
3	49 sec	0 nm	1500 ft

These differences between the greater and lesser threats were selected and tested to achieve about a 75% chance, on average, of pilots being correct. The intent was to create a task that was sufficiently difficult so that pilots would use the proximate status indication. As in the traffic rating task (Task 1), all traffic varied across the videos in their angles relative to the ownship and whether or not they were changing altitude. All traffic held straight trajectories. Again, traffic did not change from proximate to non-proximate, or vice versa, during the video. Details on the traffic's behavior are provided in Appendix C.

2.4.1. *Experimental Conditions*

Between-subjects experimental conditions were the same as the traffic rating task (Task 1): proximate status indication (two levels, with indication and without indication) and traffic density (also two levels, low density and high density). For this task the low density condition had only two aircraft, specifically the lesser and greater threat converging aircraft, while the high density condition had six aircraft. The behavior of the distracter traffic was the same as in the traffic rating task (see Appendix C).

A within-subjects variable in this task was the source of the greatest threat. The two levels for this variable were proximate or non-proximate. For each pilot, half of the time the proximate aircraft was the greatest threat and half the time the non-proximate aircraft was the greatest threat.

2.4.2. *Performance Measure for Greatest Threat Task (Task 2)*

Performance measures for the greatest threat task (Task 1) were:

- Percent of trials where the pilots correctly identified the aircraft that represented the greatest threat in the videos.

- The pilot's rating of their confidence in correctly identifying the greatest threat aircraft.

Performance on this task was measured by whether or not pilots correctly selected the aircraft with the greatest threat. The experimental design of the task indicates whether the proximate status indication can interfere with assessing threat. For example, if pilots assume that the proximate status indication represents a low-level alert, then pilots in the with-indication condition will pick the proximate aircraft as the greatest threat when in fact the non-proximate aircraft is the greatest threat, resulting in the proportion correct for non-proximate greatest threats being lower than the proportion correct for proximate greatest threats. In contrast, participants in the without-indication condition will show no difference in the proportions of correct responses between non-proximate and proximate greatest threats.

If pilots cannot tell which aircraft is the greatest threat except by the proximate status indication, then, pilots in the with-indication condition will be correct at least when the proximate aircraft is the greatest threat, while incorrect when the non-proximate aircraft is the greatest threat. However, pilots in the without-indication condition will perform poorly regardless of which aircraft was the greatest threat.

Pilots were also asked to rate their confidence in their selections of the aircraft with the greatest threat. The confidence scale ranged from 1 for "Complete Guess" to 7 for "Absolutely Certain." It is possible that performance is poor for a condition, but pilots realize this. If performance is poor and pilots realize it, then pilots would not be expected to act on their interpretations and thereby misuse the traffic display. On the other hand, if performance is poor but pilots have high confidence, then it suggests that pilots may act on their incorrect interpretations.

2.5. Task 3: Operational Experience

The purpose of the third task was to gather pilots' subjective opinions based on their operational experiences with the proximate status indication; what it is used for, and how it may aid or interfere with traffic-related activities. These data were intended to be used to identify any potential functions beyond those tested in Tasks 1 and 2 and to assist in interpreting the results from the other tasks.

Pilot's subjective opinions on their operational experiences were gathered with:

- Forced-choice response regarding the usefulness of the proximate status indication.
- Open-ended responses describing situations where the proximate status indication is useful.
- Forced-choice response regarding experiences of the proximate status indication causing confusion or created complications.
- Open-ended responses describing situations where the proximate status indication created confusion or complications and what would clear up the confusion or complications.

Participants were first asked the following question (Note: bold print below was present in the text seen by participants):

> Based on your **operational flight experience**, do you feel that distinguishing traffic with ◆ and the ◇ symbols on TCAS traffic displays is useful?

Participants who answered "yes" to this question were asked to "describe a situation where the distinction is useful." Participants who answered "no" were asked to "explain further, with examples if possible."

Participants were then asked the following question (Note: bold print below was present in the text seen by participants):

> Similarly, based on your **operational flight experience**, are there any situation(s) when you felt that the distinction between  and the  symbols on TCAS traffic displays caused confusion or created complications?

Participants who answered "yes" to this question were asked to "describe situations where the distinction created confusion or complications." Participants were also asked, "What changes to the two symbols above would help clear up the confusion or complications?"

2.6. Task 4: Knowledge of TCAS Symbology

The purpose of the fourth, and last, task in the study was to assess pilot knowledge and understanding of the proximate status indication. This task consisted of eight true-false factual questions on what was described to the pilots as "the definitions of TCAS symbols." Answers to these questions yield a score for knowledge of the meaning of the:

- TA symbol (in contrast to the proximate symbol).
- Proximate symbol (in contrast to the non-proximate symbol).

Four of the items compared the TA symbol (yellow circle) to the proximate symbol (filled diamond) and four compared the proximate symbol (filled diamond) to the symbol for non-proximate traffic (unfilled diamond). Among each four, the first and third items distinguished threat from non-threat symbols. For example, the items comparing the proximate to non-proximate symbols were the following:

>  is always a more imminent collision threat than .
>
>  always requires more prompt awareness by you than .

The second item in each set of four distinguished one symbol from another in terms of proximity. The following item is comparing the proximate to non-proximate symbols (Note: italic print below was present in the text seen by participants):

>  is always *within* a certain distance and altitude boundary around your own aircraft, whereas  is *outside* that boundary.

A final item was included to provide a validity check on the knowledge questions.

>  always requires you follow a vertical speed command

If the logic questions are a valid measure of TCAS knowledge, then the vast majority of pilots should mark the above false for both proximate and TA symbols. Only an RA symbol implies pilot must follow a vertical speed command.

The items for TA versus proximate symbols were identical, except that TA symbols replaced proximate symbols, and proximate symbols replaced non-proximate symbols. See Appendix A for the full list of questions.

For each item, the percent of pilots who believed each of these statements to be true was determined. Overall symbol knowledge was measured by the percent correct score across the four TA symbol questions and across the four proximate symbol questions.

2.7. Debriefing

Following completion of all tasks, pilots were presented with a debriefing page that described the purpose of the study (see Appendix A, *Final Pages*). The page also asked pilots force-choice questions about the performance of the web site and the realism of the tasks, and provided space for written comments. The answers to these questions are analyzed in Appendix E.

3. RESULTS

3.1. Task 1: Traffic Rating

The objective of the traffic rating task (Task 1) was to measure the degree to which the proximate status indication aids pilot assessment of the threat and potential for visual acquisition of traffic. One hundred and ten pilots completed this task, where they provided ratings of the threat and the potential for visual acquisition of traffic in twenty videos. Overall, ratings of threat were relatively consistent with actual threat levels, with an average R^2 of 0.47. This is significantly higher than pilots could theoretically achieve if they only considered the proximate status (R^2 = 0.18, $p < 0.0001$) or if they only considered range (R^2 = 0.30, $p < 0.0001$) or relative speed (R^2 = 0.41, $p = 0.0002$); it is also significantly better than combining proximate status indication with a categorical representation of speed (R^2 = 0.41, $p = 0.0004$; see Appendix C.1, *Theoretical Pilot Performance*, for details on estimating theoretical pilot performance).

Overall ratings of potential for visual acquisition were similarly consistent with the actual potential for visual acquisition (average R^2 = 0.48), but not as high as might be expected. This value of R^2 is significantly lower than what pilots would theoretically achieve by simply classifying all proximate traffic as visible and non-proximate traffic as not visible (R^2 = 0.59, $p <$ 0.0001).

Performance for rating threat and the potential for visual acquisition was not significantly correlated with pilot experience as indicated by the background questions (total flight hours, flight hours with TCAS, time since last TCAS training, frequency of experiencing TAs and RAs operationally, lowest $p = 0.0625$).

3.1.1. Effects of the Proximate Status Indication on Performance

A proximate status indication by traffic density analysis of variance (ANOVA) revealed no significant main effects or interactions concerning the proximate status indication on the consistency of the ratings with actual threat (minimum $p = 0.605$). In other words, having filled and unfilled symbols did not help pilots assess the threat of traffic.

As with rating of threat, a proximate status indication by traffic density ANOVA revealed no significant main effects or interactions concerning the proximate status indication on the consistency of the ratings with the actual potential for visual acquisition (minimum $p = 0.548$). So, symbol fill did not help pilots assess the traffic's potential for visual acquisition.

3.1.2. Effects on Strategy

The weights for the regression equations give some insight into how pilots evaluate threat and potential for visual acquisition from a traffic display. For threat, time to closest point of approach was decomposed into range and speed coefficients. A mixed-design ANOVA revealed a significant main effect of parameter (F(2.3, 266.9[3]) = 62.61, $p < 0.001$).

[3] The Greenhouse-Geisser correction was applied for any analysis of a within-subject independent variable with a significantly non-spherical dependent variable. This results in fractional degrees of freedom.

Table 5 lists the average weights for each rating. To allow direct comparison of the weights with each other, the weights reported here were standardized (Pedhazur, 1982), and any negative values were converted to positive values. For rating of threat, all coefficients are significantly different from zero, indicating that pilots are generally taking into account all parameters in their threat assessments. However, pilots weighed range significantly more than speed ($F(1,106) = 183.86$, $p < 0.0001$). This implies that while pilots are combining range and speed to get some approximation of time to closest point of approach, they are overemphasizing range. The relative weights for lateral and vertical miss distances are hard to interpret since they likely depend on the actual miss distances, which were arbitrary values in this experiment.

Table 5. Overall weights for rating traffic.

Rating	Coefficient	Standardized Weight
Threat	Range (B_r)	0.561
	Speed (B_s)	0.271[a]
	Lateral Miss Distance (B_h)	0.246[a]
	Vertical Miss Distance (B_v)	0.342
Potential for visual acquisition	Range (B_r)	0.504
	Ground (B_g)	0.093[b]
	Range-by-ground (B_{rg})	0.315

[a]Not significantly different from each other

[b]Not significantly different from zero.

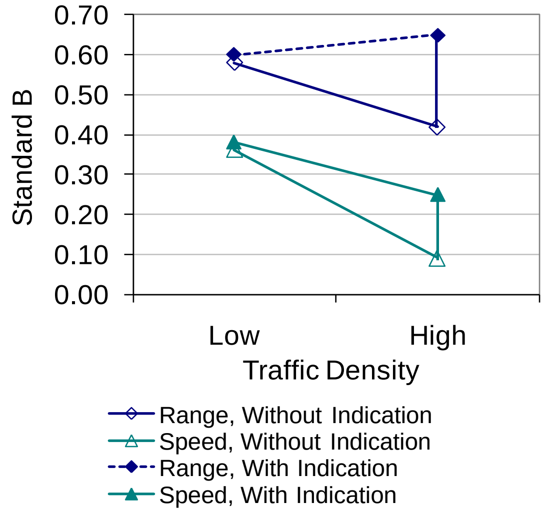
In rating potential for visual acquisition, pilots weighed range the most, but also significantly weighed the range-by-ground interaction, implying they expect the potential for visual acquisition to drop off quicker for traffic below the horizon. It seems reasonable that ground clutter does in fact cause the potential for visual acquisition to drop off faster with increasing distance than clear sky.

While there were no differences in the R^2 values for traffic density or proximate status indication, the ANOVA for the weights revealed a significant proximate status indication by traffic density by parameter interaction for rating of threat, indicating that the relative weight pilots place on each parameter depends jointly on the traffic density and whether they had the proximate status indication or not.

The two graphs in Figure 4 show the mean weights illustrating this interaction; the top graph shows the means for range and speed, and the bottom graph shows the miss distances. In these graphs and all other graphs of means in this report, points connected by solid lines, including vertical lines, are significantly different from each other, while points connected with dashed lines are not significantly different from each other.

The interactions and means in Figure 4 imply pilots with and without the proximate status indication apply different strategies for dealing with the increased cognitive demands imposed by higher traffic densities. With low traffic density, pilots in either proximate status indication condition (with and without indication) used essentially the same weights for all parameters. However with high traffic density, those in the without-indication condition, reduce weight on range, speed, and vertical miss distance and increase weight on lateral miss distance. Those in the with-indication condition, reduce weight on speed only, and not as much as those in the without-indication condition.

Traffic density and the proximate status indication had no significant main effect or interaction for the coefficients for potential for visual acquisition.



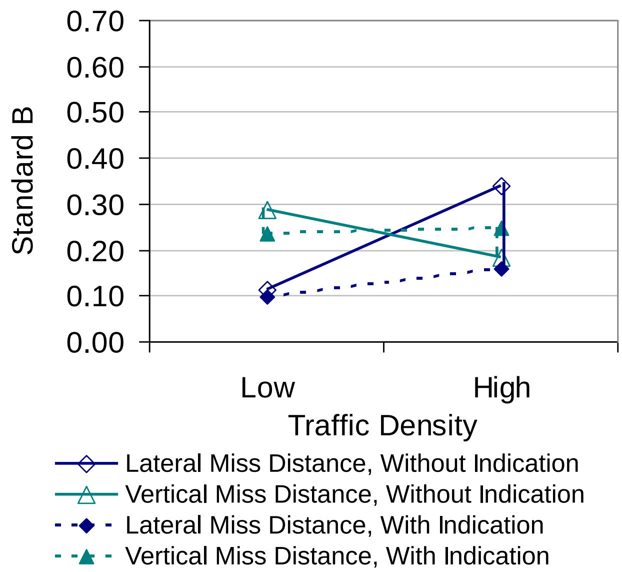


Figure 4. Mean weights for ratings of threat.

3.1.3. *Average Ratings*

A proximate status indication by traffic density by aircraft proximity (proximate or non-proximate) repeated measures ANOVA compared the average ratings of threat. On average, pilots rated proximate traffic to be more threatening ($M = 8.10$) than non-proximate traffic ($M = 5.16$, $F(1,106) = 631.4$, $p < 0.0001$). That is, regardless of whether pilots had or did not have the proximate status indication, pilots regarded traffic within six miles range and 1200 feet relative altitude to be more of a threat on average than traffic outside these bounds. This is consistent with the design of the task where traffic proximity was correlated with the potential to become a TA. The ANOVA also found a significant three-way interaction ($F(1,106) = 6.857$, $p = 0.010$). Figure 5 illustrates this interaction.

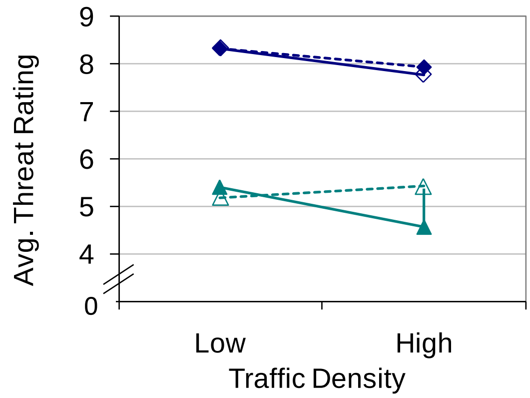


Figure 5. Ratings of threat across conditions.

For proximate traffic, an increase in traffic density decreased the perceived threat if there was no proximate status indication ($t(106) = -2.179$, $p = 0.0339$). In contrast, for non-proximate traffic, an increase in traffic density decreased the perceived threat if there *was* a proximate status indication ($t(106) = -2.106$, $p = 0.0399$). In essence, when both proximate and non-proximate traffic were unfilled, more distractor traffic made the proximate traffic appear relatively less threatening. On the other hand, when proximate traffic were filled and non-proximate traffic were not filled, more distractor traffic made non-proximate traffic appear relatively less threatening. These results are consistent with the proximate status indication enhancing the apparent threat of proximate traffic. No other effects or interactions were significant.

A proximate status indication by traffic density by aircraft proximity (proximate or non-proximate) repeated measures ANOVA compared the average ratings of potential for visual acquisition. On average, pilots' ratings suggested that proximate (closer) would be visually acquired more easily than non-proximate (distant) traffic (proximate: $M = 6.80$; non-proximate: $M = 5.29$, $F(1,106) = 126.9$, $p < 0.0001$). This is consistent with closer traffic having greater potential to be visible than distant traffic. No interactions were significant.

Ratings of threat and potential for visual acquisition were not correlated on average with the order of video presentations among the pilots (respectively, average $r = -0.009$, $t(109) = -0.384$, $p = 0.701$, and $r = 0.013$, $t(108) = 0.529$, $p = 0.598$).

3.1.4. Relation to Knowledge of TCAS Symbology

Pilot performance on rating threats in the traffic rating task (Task 1) did not appear to be influenced by pilot knowledge of TCAS symbology (as measured in Task 4). There was no significant correlation between knowledge of TCAS symbology and the consistency of the ratings of threat with actual threat (proximate knowledge score $r = 0.059$, $n = 100$, $p = 0.563$; TA knowledge score $r = 0.019$, $n = 100$, $p = 0.854$). Likewise, pilot performance on rating the potential for visual acquisition did not appear to be influenced by their knowledge of TCAS symbology. There was no significant correlation between knowledge of TCAS symbology and the consistency of the ratings of potential for visual acquisition with actual potential for visual acquisition (proximate knowledge score $r = -0.067$, $n = 99$, $p = 0.508$; TA knowledge score $r = 0.101$, $n = 100$, $p = 0.320$).

There was the concern that pilots who were knowledgeable about TCAS symbology in the without indication condition might be confused by seeing proximate traffic as unfilled symbols because TCAS would show the proximate traffic as filled symbols. If this were the case, pilots who were knowledgeable about TCAS symbology in the without indication condition would have poorer performance on rating threat and potential for visual acquisition than pilots who knowledgeable about TCAS symbology in the with indication condition.

Analyses to test this concern did not reveal this pattern. The consistency of the ratings of threat with actual threat was regressed on the traffic rating task (Task 1) experimental conditions, the knowledge of TCAS symbology scores, and interactions among the conditions and knowledge of TCAS symbology. There were no significant interaction of knowledge of TCAS symbology with any of the experimental conditions (for proximate knowledge $R = 0.171$, $F(7,92) = 0.674$, $p = 0.694$; for TA knowledge $R = 0.221$, $F(7,92) = 0.398$, $p = 0.901$). Similarly, the consistency of the ratings of potential for visual acquisition with actual potential for visual acquisition was also regressed on the traffic rating task experimental conditions, the knowledge of TCAS symbology scores, and interactions among the conditions and knowledge of TCAS symbology. This also revealed no significant interaction of knowledge of TCAS symbology with any of the experimental conditions (for proximate knowledge $R = 0.173$, $F(7,91) = 0.402$, $p = 0.899$; for TA knowledge $R = 0.227$, $F(7,91) = 0.708$, $p = 0.666$). That is, that pilots who were knowledgeable about TCAS symbology did not perform differently in the without indication condition than in the with indication condition.

The knowledge of TCAS symbology scores were regressed on the pilots' standardized regression weights for range, speed, and miss distances (see Equation (3)). These regressions were not significant (for proximate knowledge $R = 0.208$, $F(4,95) = 1.430$, $p = 0.239$; for TA knowledge $R = 0.175$, $F(4,95) = 0.754$, $p = 0.558$). There is no evidence that pilots with greater knowledge of TCAS symbology adopted different strategies for estimating threat than other pilots (e.g., more equally weighing speed and range).

3.2. Task 2: Greatest Threat

The objective of the greatest threat task (Task 2) was to measure the degree to which the proximate status indication potentially interferes with (in contrast to aiding) the pilot assessment of traffic threat. One hundred and two pilots completed this task, where they identified the aircraft that represented the greatest threat in 12 videos. On average, pilots selected the correct greatest threat aircraft 69.9% of the time, close to the intended rate of 75%. Overall, the task was difficult, but not impossible, so any benefits afforded by the proximate status indication should be exhibited by pilots with the proximate status indication having a higher average percent correct than those without. Within each pilot's responses, the chance of being correct was not related to the order of presentation of the scenarios (average $r = -0.028$, $t(99) = -0.797$, $p = 0.427$). This lack of an order effect is not surprising given pilots received no feedback on their performance. In only one case did a pilot chose a distracter aircraft as the greatest threat; in all other cases the pilots chose one of the converging aircraft.

Correct selection of the greatest threat was not significantly correlated with pilot experience as indicated by the background questions (total flight hours, flight hours with TCAS, time since last TCAS training, frequency of experiencing RAs operationally), except that the more TAs a pilot reported experiencing, the *less* likely she or he would correctly identify a non-proximate aircraft as the greatest threat ($r = –0.291$, $n = 101$, $p = 0.0030$). Possibly, having experience with TAs, which are generally more likely to emerge from nearby traffic, makes pilots somewhat more susceptible to less frequent cases where a relatively distant traffic poses a greater threat.

3.2.1. *Effects of the Proximate Status Indication on Performance*

A mixed-design proximate status indication by traffic density by source of the greatest threat ANOVA found that pilots tended to correctly identify greatest-threat aircraft that were proximate (closer) (92% correct on average, main effect $F(1,97) = 268.1$, $p < 0.0001$), but they were equally likely to be wrong or right in identifying greatest-threat aircraft that were non-proximate (farther) (46% correct on average, not significantly different from a chance-level of performance of 50%, $t(101) = -1.56$, $p = 0.123$). That is, when the greater threat aircraft was within 6 miles and 1200 feet, pilots were almost always correct, but when the greater threat aircraft was outside 6 miles or 1200 feet, pilot performance was no better than random guessing. This was true whether the pilots had a proximate status indication (symbol fill) or not. Overall, pilots chose the proximate aircraft 74% of the time, rather than the correct proportion of 50%.

Whether the greatest threat was from a proximate or non-proximate source, pilots were on average correct 9% more often in the without-indication condition (i.e., all symbols unfilled) than in the with-indication condition (i.e., symbols for proximate traffic filled, $F(1,97) = 6.403$, $p = 0.013$). That is, the data suggest that the use of fill to indicate proximity interfered with accurate comparisons of aircraft regardless of the proximity of the greatest threat.

There was no effect of traffic density ($p = 0.210$) on identifying the greatest-threat aircraft. The interactions were not significant (smallest $p = 0.204$).

To explore the effects in greater detail, two more independent variables were added to the ANOVA:

- Behavior of the greater threat, which may or may not include altitude changes.
- Behavior of the lesser threat, which may have a long time until closest point of approach, a high horizontal miss distance, or a high vertical miss distance.

The analysis again found that pilots were on average correct more often in the without-indication condition than in the with-indication condition ($F(1,85) = 5.251$, $p = 0.024$). However, there was a significant interaction of proximate status indication with the behavior of the greater threat, as illustrated in Figure 6 ($F(1,85) = 4.155$, $p = 0.045$), where the impact of the proximate status indication depended on the threat's vertical motion.

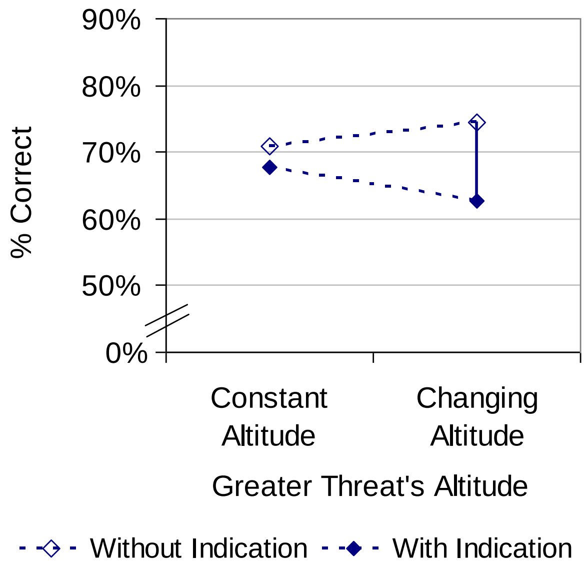


Figure 6. Interaction of greater threat's behavior and indication.

While there is no significant difference in pilot accuracy when the greater threat maintains level flight, accuracy diverges to a 12% gap in favor of no proximate status indication when the greater threat was changing altitude ($t(99) = 3.059$, $p = 0.0032$). The results indicate that the proximate status indication was detrimental to threat comparisons when the traffic trajectory included vertical motion. Having the proximate status indication on the traffic display results in pilots being less accurate at identifying the greatest threat if the greatest threat was climbing or descending. The data show this to be the case whether the greater threat was proximate or non-proximate (three-way interaction $F(1,85) = 0.558$, $p = 0.457$).

The ANOVA also revealed that traffic density interacted with traffic behavior, both of the greater threat ($F(1,85) = 4.774$, $p = 0.032$) and the lesser threat ($F(2,170) = 3.857$, $p = 0.030$). At high traffic density, accuracy was better when the greater threat changed altitude than when it maintained a constant altitude ($t(99) = -2.156$, $p = 0.035$). That is, when the greater threat aircraft was climbing or descending, pilots more often correctly identified the greatest threat when there were distractors than when there were not. Accuracy for the lesser threat with a high horizontal miss distance was higher with high density than low density ($t(99) = -3.250$, $p = 0.0019$) . That is, when the lesser threat aircraft was going to miss the ownship, pilots more often correctly identified the greatest threat when there were distractors than when there were not. Other comparisons were not significant. These interactions may result from shifts in threat estimation strategies with increased cognitive demands as described in Section 3.1.2.

Finally the analysis revealed a significant three-way interaction between traffic behavior and proximity of the greater threat ($F(2,170) = 5.918$, $p = 0.003$), indicating that the effects of traffic behavior depended whether the greater threat was proximate (closer) or not, as shown in Figure 7. This probably reflects the difficulty of the chosen specific scenarios combined with ceiling effects for conditions when the proximate aircraft was correct. That is, when the proximate aircraft was the greatest threat, pilot accuracy approached 100 percent. With performance unable to mathematically exceed 100 percent, the differences due to traffic behavior are less evident.

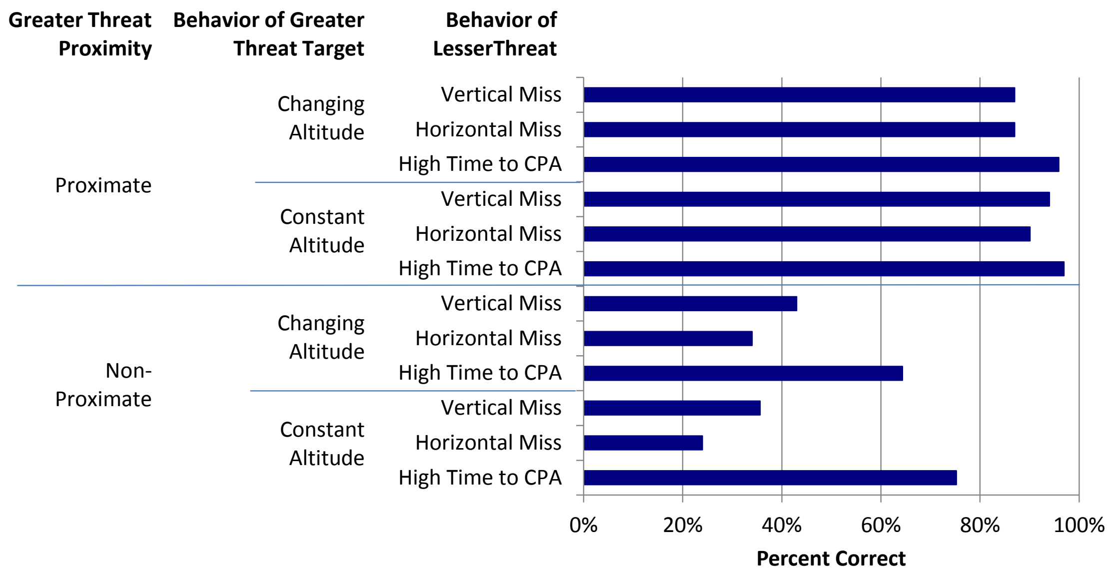


Figure 7. Mean percent correct.

3.2.2. Effects on Confidence

Overall pilot confidence was moderate, averaging 4.30 on a 1-7 scale, where 1 was "complete guess" and 7 was "absolutely certain." Pilots apparently recognized that this was a non-trivial task, but they did not feel that they were simply guessing on average. This was true even when the non-proximate aircraft was the greatest threat (average confidence rating 4.13), which corresponded to performance that was in fact not significantly different from guessing. Within each pilot's responses, there is no significant average correlation between confidence and the probability of being correct (average $r = 0.0612$, $t(98) = 1.908$, $p = 0.059$). Among pilots, there was a slight tendency for those with greater average confidence to be correct slightly more often ($r = 0.220$, $n = 101$, $p = 0.0271$). That is, pilots cannot rely on their sense of confidence to determine if they have correctly identifying the aircraft that represents the greatest threat.

A proximate status indication by traffic density by source of the greatest threat ANOVA on the confidence scores found a significant traffic density by source of the greatest threat interaction ($F(1,97) = 12.89$, $p = 0.001$), indicating that effects of the proximity of the greatest threat on confidence depended on traffic density.

As illustrated in Figure 8, when traffic density was high, pilots were more confident when the proximate aircraft was the greatest threat than when the non-proximate aircraft was the greatest threat. When density was low, there was no difference. It seems that when there are no distractors and pilots can study each aircraft more carefully, pilots find it easier to convince themselves they are right about non-proximate threats or they second-guess themselves more about proximate threats.

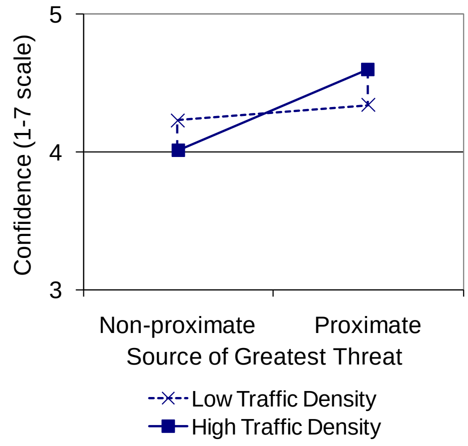


Figure 8. Mean confidence ratings.

There were no significant effects or interactions involving proximate status indication (smallest $p = 0.454$). There was no evidence that the proximate status indication affects pilot confidence in ratings of threat.

Confidence was also not significantly correlated with pilot experience as indicated by the background questions (total flight hours, flight hours with TCAS, time since last TCAS training, frequency of experiencing TAs and RAs operationally; minimum $p = 0.162$). Within each pilot's responses, there was a slight tendency for confidence to decrease through the trials (average $r = -0.159$, $t(99) = -4.938$, $p < 0.0001$). Perhaps as pilots studied more scenarios, they became aware of some of subtle trade-offs between speed, range, and miss distances, and thus experienced a reduction in confidence. However, as recounted in 3.2, the decrease in confidence did not reflect actual pilot performance.

3.2.3. Relation to Knowledge of TCAS Symbology

A pilot's proportion of correct responses for greater-threat non-proximate aircraft was regressed on their answers to the questions in the knowledge of TCAS symbology task (Task 4) to measure how pilots' knowledge of TCAS related to their assessments of threat. The relation of the answers to the proportion of correct responses was weak but significant ($R = 0.359$, $F(6,93) = 2.299$, $p = 0.041$). Analysis of the regression weights indicated pilots were more likely to correctly identify the greater-threat non-proximate aircraft if the pilots understood that a proximate symbol represents traffic within a certain boundary, and did not represent a threat level ($B = 0.157$, $t(98) = 2.901$, $p = 0.005$). The bivariate relation for this item was significant but fairly weak ($r = 0.258$, $n = 100$, $p = 0.005$). Exact knowledge of the meaning of the proximate status indication may help pilots avoid the less frequent cases where a relatively distant aircraft poses a greater actual threat than a nearby aircraft. Such pilots are more likely to realize that an aircraft shown as a filled symbol merely has closer proximity than an aircraft shown with a non-filled symbol, and not necessarily a greater threat.

No other knowledge items were significantly related to correct responses for greater-threat non-proximate aircraft. An identical regression on the proportion of correct responses for greater-threat proximate aircraft was not significant ($R = 0.267$, $F(6,93) = 1.194$, $p = 0.317$).

3.3. Task 3: Operational Experience

The objective of the operational experience task (Task 3) was to gather pilots' subjective opinions based on their operational experiences with the proximate status indication. One hundred pilots completed this task, where they provided their subjective opinions by answering forced-choice and open-ended questions about the operation use of the proximate status indication. Of these, 93 provided a response to at least one of the open-ended questions. One pilot skipped this task entirely and proceeded to the knowledge of TCAS symbology task (Task 4). This pilot was not included in the analysis of the operational experience task.

3.3.1. *Coding of Open-ended Responses*

In this task, participants provided responses to open-ended questions regarding two topics:

- The usefulness of the proximate status indication on TCAS displays.
- Any situation when the proximate status indication on TCAS displays caused confusion or created complications.

Participants' open ended responses on both topics were pooled for each participant and reviewed, and then a categorization scheme was developed. Using this scheme, two judges independently classified the responses into six categories, three for the reported function of the proximate status indication and three for problems with or improvements for the proximate status indication. The three function categories were:

- Guides attention.
- Indicates potential threats.
- Guides visual search.

Responses classified in the guides visual search or indicates potential threats categories were automatically also classified as in the guides attention category. The three problem or improvement categories were:

- Show more information, that is, additional traffic information should be encoded in the symbol.
- Need different coding, that is, additional or alternative graphic attributes, such as color, should be used to indicate the information the symbol presents.
- Poor threat indication, that is, the proximity is not a reliable indication of traffic threat.

Inter-judge (or inter-rater) reliability on the categories ranged from 93% to 98%, and the inter-judge correlations ranged from 0.763 to 0.898, except for the category of statements that the proximate status indication is a poor threat indication. The poor threat indication category had an inter-judge correlation of 0.394, suggesting that it was difficult to tease out pilot opinions for this category from the free-response answers. Classification disagreements were resolved by consensus. Appendix D provides the categorization scheme and details the results for the test for inter-judge reliability. It also addresses responses that did not fit in any category, which potentially indicate additional operational functions for the proximate status indication.

3.3.2. *Reported Functions of Proximate Status Indication*

Table 6 shows the frequency of the function categories for each response to the force-choice question concerning the usefulness of the proximate status indication. Function categories apply to the combined responses of each pilot to all open-ended questions. The columns in the table headed with "#" are the raw frequencies of pilots in each category. The percentages in the columns are the percent of pilots in each category for each response (yes or no) to the forced-choice question. A single pilot's open-ended response may have more than one category, so the percentages in the columns do not total to 100. In contrast, each pilot can only respond yes or no to the forced choice question, thus the total frequency ("#") column is the sum of the yes and no frequency columns. The no open response row shows the number of pilots who answered the forced choice questions, but provided no entry in any text box for open-ended responses. The no explicit function row show the number pilots who provided an open-ended response in at least one text box, but whose response did not fit in any of the categories for function. For example, of the 84 pilots who indicated that the proximate status indication was useful, 21 did not provide a classifiable function for the proximate status. Uncategorized responses and the potential for additional operational functions are evaluated in Appendix D.

Table 6. Response breakdown of function response categories.

	Do you feel that distinguishing traffic with and the symbols on TCAS traffic displays is useful?					
	Yes		**No**		**Total**	
Function Categories	#	%	#	%	#	%
Guides Attention	58	69	1	6	59	59
Indicates Potential Threats	38	45	0	0	38	38
Guides Visual Search	9	11	0	0	9	9
No Explicit Function	21	25	13	76	34	34
No Open Response	5	6	2	12	7	7
Total	84	--	16	--	100	--

Of particular interest are the functions for the proximate status described by pilots who felt it was useful (the yes columns in Table 6). Of the 100 pilots that completed the operational experience task (i.e., at least answered the forced–choice questions in Task 3), 84 regarded the proximate status indication as useful. In reading and categorizing these 84 pilots' free responses, 58 (69%) of these pilots appear to say the proximate status indication helps guide attention. This includes 38 (45%) who specifically said it helps indicate potential threats, such as this response:

> "It distinguishes [which] target is possibly considered a bigger threat."

Nine (11%) said the proximate status indication helps guide visual search, such as this pilot:

> "I… am more likely to make an effort to begin visual acquisition."

The remaining 21 pilots who gave open-ended responses gave no explicit function, such as this one:

> "It helps for a quick glance to see something of note."

No one specifically said they used the proximate status indication to determine whether traffic might be visible.

3.3.3. Reported Problems or Improvements for the Proximate Status Indicator

Table 7 shows the frequency of the problem or improvements categories for each response to the force-choice question concerning confusion or complications caused by the proximate status indication.

Table 7. Response breakdown problem or improvement response categories.

Problem or Improvements Categories	Are there any situation(s) when you felt that the distinction between ◆ and the ◇ symbols on TCAS traffic displays caused confusion or created complications? Yes		No		Total	
	#	%	#	%	#	%
Show More Information	4	44	1	1	5	5
Need Different Coding	3	33	12	13	15	15
Poor Threat Indication*	0	0	3	3	3	3
No Explicit Problem or Improvement	1	11	70	76	71	71
No Response	1	11	6	6	7	7
Total	9	100	91	100	100	100

*This category exhibited low inter-judge reliability. See Section 3.3.1.

The vast majority of pilots (91%) responded with "no" to forced-choice the question in Table 7 regarding their subjective opinions based on their operational experiences with the proximate status indication. That is, these pilots reported that there was no situation where the proximate status indication has caused confusion or created complications for the pilot. These subjective results conflict with the objective results of the greatest threat task (Task 2), where the proximate status indication did in fact reduce the accuracy of threat assessments (see Section 4 for discussion).

As with the function categories, the problem and improvement categories apply to the combined responses of each pilot to all open-ended questions. Since the opinion of 91% of the pilots was that proximate status indication presented no problems, their open-ended responses usually did not include any explicit description of problems or improvements. Rather, the responses usually only described functions for proximate status indication, which pilots were also asked about. Thus, most of these pilots' open-ended responses (76%) were categorized as no explicit problem or improvement.

In responses to the forced-choice questions asking for pilots' subjective opinions, only nine out of the 100 pilots reported that the proximate status indication could be potentially confusing or complicating. Of this small proportion of pilots who thought that there may be a problem, none explicitly indicated in their responses to the open-ended opinion questions that the proximate status indication could lead to inaccuracy in comparing the threat levels of traffic. These subjective results conflict with the objective results of the greatest threat task (Task 2) where the proximate status indication did in fact reduce the accuracy of threat assessments when comparing the threat levels of traffic (see Section 4 for discussion).

Of the nine that indicated in their forced-choice response that there may a problem, four wrote in their open-ended responses that the traffic representation should show more information. For example, one pilot wrote:

> "Perhaps a short vector symbol on the intruder showing relative closure bearing."

This does not seem related to the accuracy problems seen in the greatest threat task (Task 2). Showing additional information in the symbol probably does not address the potential for information already in the symbol to lead to inaccuracy.

Three of the nine pilots suggested in their open-ended responses that the symbology should have different coding, in addition to or other than symbol fill. For example one pilot wrote:

"Color coding is best."

This also does not seem related to the accuracy problems seen in the greatest threat task (Task 2). Showing the same information differently would not necessarily improve the accuracy. Indeed, it would seem pilots were seeking to make the information more visually apparent, which could aggravate the inaccuracy problem

An additional 12 pilots who did not see any problems with the proximate status indication nonetheless also suggested changing the symbology. Apparently, these pilots felt that, while the symbology was not problematic, it could still be improved. Generally these pilots suggested coding that would make the proximate status more obvious. As before, this also does not seem related to the accuracy problems seen in the greatest threat task (Task 2).

Out of all 100 pilots, a few suggested the proximate status indication was a poor threat indication. These could be pilots who were aware that the proximate status indication could lead to inaccurate comparisons of traffic threat, although none explicitly describe such a situation. For example, one pilot wrote:

"Doesn't provide a lot of trend information and can be misleading."

Three responses were assigned by consensus to this category by the two judges who categorized the comments. However, there is likely some inaccuracy in that frequency given the low reliability of this category of response. Four pilots (4%) were classified this way by either of the two judges when they categorized the comments independently, so that may be an approximate upper bound of the number of pilots who feel the proximate status indication is a poor threat indication. Four percent still constitutes a very small percentage of all pilots aware that the proximate status indication could lead to inaccurate comparisons of traffic threat.

Overall, results from this task indicate that pilots were generally unaware that the proximate status indication may be ineffective or even potentially detrimental for assessing the threat of traffic, as found in the traffic rating and greatest threat tasks (Tasks 1 and 2).

3.4. Task 4: Knowledge of TCAS Symbology Results

The objective of the knowledge of TCAS symbology task (Task 4) was to assess pilot knowledge and understanding of the proximate status indication. One hundred one pilots completed this task, where they answered true-false factual questions on the definitions of TCAS symbols. The data from the knowledge of TCAS symbology task (Task 4) were analyzed with a multivariate ANOVA with symbols as the independent variable (TA-versus-proximate symbol and proximate-versus-non-proximate symbol), and the four items used for each as the dependent variables. Overall performance on TA-versus-proximate symbol was better than proximate-versus-non-proximate symbol (79% correct versus 57% correct, Wilks Lambda = 0.765, $F(4,94) = 7.216$, $p < 0.001$). Table 8 shows the percent of pilots agreeing with each item. A check mark next to the percent value indicates that the item was true, so pilots agreeing with that statement were correct. An X next to the percent indicates that the item was false, so pilots agreeing with that statement were incorrect.

Table 8. Pilots agreeing with each item.

Item	 vs. 	 vs. 
Is always a more imminent collision threat	85% ✓	65% ✗
Always requires more prompt awareness by you	85% ✓	68% ✗
Is always within a certain distance and altitude	47% ✗	64% ✓
Always requires you follow a vertical speed command	7% ✗	3% ✗

✓ Agreeing is *correct*
✗ Agreeing is *incorrect.*

Only a small number of participants got the fourth item incorrect, implying the task was a valid measure of pilot knowledge of TCAS symbology as discussed earlier in Section 2.6.

Most participants agreed that an aircraft represented by a proximate symbol is always a more imminent collision threat, requires more prompt awareness, and is closer than an aircraft represented by a non-proximate symbol. In fact, only the third item is a correct statement about the proximate symbol. Perhaps surprisingly, about half of the pilots agreed that an aircraft represented by a *TA symbol* must also be closer than an aircraft represented by a proximate symbol, which is not a true statement. This could suggest that up to half of pilots may be equating closeness with threat, as defined by TCAS. That is, many pilots may not have considered the very real possibility of more distant aircraft being a greater threat than close aircraft due to the more distant aircraft having a higher closing speed (e.g., as in Figure 1).

Performance on the knowledge questions was not related to the experimental conditions in either of the two video tasks, traffic rating and greatest threat (smallest multivariate $p = 0.320$). In other words, the experimental conditions did not lead to pilots misunderstanding the meanings of these TCAS symbols.

Knowledge of TCAS symbology was not significantly related to pilot experience variables such as flight hours, time since most recent TCAS training, or frequency of experiencing alerts (smallest $p = 0.215$).

4. DISCUSSION

In summary, the results suggest that indicating the proximate status provides no performance benefit for recognizing either the threat or potential for visual acquisition of traffic, and it may interfere with comparisons of traffic when determining which aircraft is a more imminent threat (as defined by the TCAS alert algorithm). Traffic lateral and vertical closeness (i.e., proximity) may be important for assessing threat and potential for visual acquisition, but pilots can also effectively get this information from a display without a proximate status indication by using the display range rings and altitude tags. Despite the performance data showing no benefit of the proximate status indication, the majority of pilots nonetheless indicated that, in their opinion, they considered the proximate status indication useful for attention allocation. They understand it represents proximity, but believe it also represents threat (i.e., a relatively greater potential for collision that requires more prompt awareness).

In the traffic rating task (Task 1), the presence of the proximate status indication on a traffic display did not significantly affect the consistency of ratings of threat and potential for visual acquisition of traffic with actual threat and potential for visual acquisition. Analysis of the weights pilots placed on the parameters of threat indicated that both groups of pilots functionally incorporated traffic closeness into their threat assessments. Pilots without the proximate status indication apparently did as well as pilots with the proximate status indication by observing the traffic's position on the display and its altitude tag.

The differences in weights associated with differences in traffic density suggest that the proximate status indication allows pilots to consider more parameters when there is a lot of traffic on the display resulting in relatively high cognitive demands. Yet this did not translate into better overall performance since there was no significant proximate status indication by traffic density interaction for R^2. It appears that the proximate status indication may facilitate pilots' range estimates but it also overemphasizes range. This may be because pilots associate the symbol's intensification (becoming filled) with lower ranges (less than 6 nm). The weight analysis indicated that pilots already overemphasize range, which may negate any advantage from the indication itself.

The greatest threat task (Task 2) found evidence that the proximate status indication may interfere comparing the threat levels of two aircraft. When faced with proximate and non-proximate aircraft, pilots were 12 percentage points less accurate in identifying the greatest threat among them when the aircraft were distinguished by the proximate status indication (symbol fill). This was specifically true when the greater threat aircraft was changing altitude.

This lower accuracy occurred both when the greatest threat was proximate and non-proximate. The effect is perhaps surprising given that symbol fill incorporates vertical information (i.e., that the traffic is within 1200 feet relative altitude), which might be expected to help vertical situation awareness. Instead, it seems that the presence of filled and unfilled symbols in a display interferes with a pilot's ability to project an aircraft's vertical trajectory. Possibly the mental processing of the meaning of fill diverts cognitive resources from fully processing the meaning of the vertical speed information in the data tag. As a result, pilots may sometimes fail to notice the arrow in the data tag indicating that the aircraft is closing on the ownship altitude. Thus, pilots underestimate the threat of such traffic.

Overall, pilots reported moderate confidence in their selections of the greatest threat, but confidence was not related to performance. Pilots who happen to be confident may thus act on their judgment of relative threat even when it is not accurate. Operationally, this may result in a non-optimal allocation of attention. For example, pilots might spend time visually searching for one aircraft when another is actually a greater threat. However, it is unclear whether a 12% difference in accuracy is an operational concern.

The traffic rating task (Task 1) did not reveal a performance difference for the proximate status indication. In contrast to the greatest threat task (Task 2), the traffic rating task presented a single converging aircraft rather than pairs, suggesting that the poorer performance for the proximate status indication in the greatest threat task is specific to comparing traffic. It may be perceptually more difficult to compare symbols on range or speed when they are visually different (filled and unfilled), even when the visual differences are redundant or irrelevant for range or speed estimations.

Results from the operational experience task (Task 3) indicate that most pilots consider the proximate status indication to be important for directing attention towards traffic of greatest threat. Pilots completed the operational experience task after completing tasks concerning the relative threats of traffic, so it is possible that that experience exaggerated the proportion of pilots who actually use the proximate status indication for threat estimation. However, this should have not diminished the frequency with which other uses would also have been mentioned. It appears that the only common function pilots have found for the proximate status indication is to direct attention towards the proximate traffic.

The operational experience task (Task 3) also found that a large majority of pilots (91%) held the opinion that the proximate indication status is useful and only a small minority (9%) held the opinion that it could be confusing or create complications. This high perceived value of the proximate status indication is not consistent with its lack of performance benefit in the traffic rating and greatest threat tasks (Tasks 1 and 2, respectively). Indeed, the greatest threat task found that the proximate status indication can have a detrimental effect under certain conditions. It is especially inconsistent given that pilots say the proximate status indication is most useful for directing attention, including for identifying potentially threatening traffic. If it is in fact useful for that function then one might expect to see performance benefits in the traffic rating and greatest threat tasks. While operator opinion in some cases predicts operator performance (Duncanson, 1994), a divergence of operator opinion and operator performance data is not uncommon, and has been observed with pilots regarding other traffic information (Hart and Loomis, 1980). Despite extensive operational experience, operators do not always accurately know what they need.

The knowledge of TCAS symbology task (Task 4) indicates that most pilots are aware that a proximate symbol means an aircraft must be relatively close, but most pilots also erroneously believe the proximate aircraft must be a relatively greater threat that requires more prompt attention. This opens the possibility of pilots misusing the proximate status indication, although there was no evidence of such misuse in the first two experiment tasks.

Pilots tend to simultaneously regard the proximate status indication as representing both proximity and threat, which makes sense if they *overemphasize proximity in determining threat.* That is, pilots may be excessively influenced by the closeness of traffic, at the expense of other considerations such as relative closing speeds, in their threat estimates. Such an interpretation is consistent with the observation that about half of the pilots also think a *TA symbol* necessarily represents greater proximity than a proximate symbol. It is also supported by the findings from the greatest threat task (Task 2) that pilots were correct far more often when the greatest threat was a proximate rather than a non-proximate aircraft, including when no proximate status indication was used. The weight analysis in the traffic rating task (Task 1) also supported these findings. The weight analysis indicated that, while pilots consider other parameters in estimating threat, they overemphasize the role of proximity in threat assessment. Finally the overemphasis of proximity is consistent with prior research that found that pilots had a "distance-over-speed bias" in threat perceptions (Xu, Rantanen, and Wickens, 2004; Xu and Rantanen, 2007).

Pilot's overemphasis of proximity in their estimates of threat may explain the inconsistency between pilots valuing the proximate status indication and its failure to provide an objective performance benefit. If pilots believe proximity is critical to threat estimates, it may be natural that they may assume that emphasizing differences in proximity will improve performance. However the results from this study show that pilots overemphasize proximity even when there is no proximate status indication. Adding the proximate status indication to the display, therefore, does not improve performance.

The tendency of pilots to overemphasize proximity in threat assessments may be a natural consequence of pilots using a plan-view display. Proximity may be more conspicuous than other parameters, such as relative closing speed. Pilots likely have observed TA symbols turning into resolution advisory (RA) symbols as an aircraft draws closer, highlighting the role of closeness in threat. It seems less likely they would notice a change in aircraft relative speed turning a TA to an RA. A pilot may imagine that, compared to a non-converging non-proximate aircraft, a non-converging proximate aircraft could quickly become an imminent collision by simply maneuvering, and thus necessarily represents a greater *potential* threat. However, this reasoning disregards that, all other things being equal, the non-proximate aircraft can turn onto a collision course with a smaller maneuver than the proximate aircraft. Thus, the overemphasis on the proximate traffic is potentially hazardous because it results in pilots incorrectly focusing on traffic that is not necessarily the greatest threat, thereby setting them up for a situation where their attention is diverted from the greatest threat.

The possibility also exists that the proximate status indication on TCAS displays has itself encouraged pilots to overemphasize proximity in threat perceptions. Indicating proximity with filled and unfilled symbols adds prominence and attentional characteristics to the symbology that visually emphasize proximity. In the operational experience task (Task 3), one pilot remarked that "there is a logical progression from open diamond to solid diamond to yellow circle to red square [that] is fairly easy to understand as far as 'threat levels.'" Pilots understand correctly that the transitions from proximate symbol to TA to RA represent increases in threat. It is reasonable that they would assume the transition between non-proximate to proximate symbols would also represent an increase on the same dimension. Given that pilots generally know that symbol fill represents a change in proximity, it is understandable that pilots would incorrectly conclude that threat is primarily a matter of proximity.

4.1. Experiment Limitations

There are limitations to this study. This study examined the usefulness of the proximate status indication as represented by symbol fill, and found no advantage for it, only a disadvantage. However, the study does not address whether symbol fill could be remapped to a different meaning than proximity. Further research is necessary as discussed below before such remapping is contemplated.

The experiment used the TCAS alert algorithm as an objective definition of threat to which to compare pilot performance. There may be other measures of threat that, for example, place more emphasis on range. However, the TCAS definition of threat is widely accepted and has proven effective in operational contexts.

It has been suggested that the real usefulness of the proximate status indication is seeing a traffic display symbol *change* from non-proximate to proximate as a cue that the aircraft is closing, and is therefore a threat. However, in the operational experience task (Task 3), only a handful of the pilots alluded in any way to using the proximate status in this manner. In any case, such a use is relevant only to TCAS. CDTI has alternative indications, such as directionality, to indicate rapidly converging traffic.

The experiment tested the proximate status indication for threat and visual acquisition assessments. The proximate status indication may have other uses. For example, it may be useful for guiding the direction of visual search, or to distinguish traffic near ownship altitude for better mental representation of traffic in three dimensions. However, no such uses were reported by pilots in the operational experience task (Task 3).

Nearly the entire study sample was air transport and high-end general aviation pilots because they were most likely to have experience with the proximate status indication. Thus, the results may not be generalizable to general aviation. However, display requirements for CDTI are the same for all types of aircraft to keep consistency across displays. In the meantime, the results of this study should only be generalized to the use of traffic displays under instrument flying rules following training similar to that given for TCAS to air transport and high-end general aviation pilots.

The web-based tasks in this study have limited operational realism. For example, traffic in the videos never turned and pilots rarely study a traffic display for a continuous 15 second period; multiple short glances over a longer time would be more realistic. However, for this to be an issue, the lack of realism must be associated with a reasonable mechanism that would yield different results. For example, there should be some explanation for why a series of quick glances at a traffic display would produce an advantage for the proximate status indication that disappears with a single 15-second gaze

4.2. Future Research Directions

To explore the usefulness of a proximate status indication, additional intended functions of the indication would need to be defined and evaluated. If a function for the proximate status indication is identified and a related performance benefit is documented, then the proximate status indication should be included on shared CDTI-TCAS displays.

Another research direction is to investigate the use of symbol fill for indicating information other than proximity or threat on CDTIs (e.g., aircraft that is selected, has high data quality, or is airborne rather than on-ground). Remapping symbol fill in CDTIs to a different meaning than in TCAS raises the following key research questions:

- What is the potential for confusion among for pilots who have learned from TCAS that fill means proximity?
- How would this work on an integrated TCAS/CDTI display?
- What issues arise if TCAS does show proximity with symbol fill while CDTI does not?

Whatever the alternative uses of symbol fill for future displays, the result of this study suggest that, given the limited visual features available in a symbol, displaying proximity graphically in the symbol is of relatively little performance benefit to the pilot in terms of assessing threat and potential for visual acquisition.

5. REFERENCES

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APPENDIX A: ADVERTISEMENT AND WEB SITE SCREENS

Newsletter Advertisement

Active TCAS-Experienced Pilots Invited to Participate in Traffic Display Study

The U.S. Department of Transportation Volpe Center is conducting an online study about traffic displays. Active, TCAS-experienced pilots are invited to participate. The study takes approximately 45 minutes to complete. Pilots will see short videos of traffic displays and answer questions about the targets on the display. Results of the study will be considered by the FAA and industry when developing guidance for future Cockpit Displays of Traffic Information.

To learn more about the study and to participate go to http://www.trafficdisplayresearch.net/. Results of the study may be presented to the RTCA, an industry group that develops avionics standards and recommendations (www.rtca.org). For further information on human factors research at the Volpe Center, go to http://www.volpe.dot.gov/hf/.

Preliminary Pages

Welcome

Traffic Display Research Study

Welcome!

Welcome to this research study on traffic displays, which is being conducted by the United States Department of Transportation Volpe Center in Cambridge, Massachusetts.

This study is open to all **licensed and current** pilots **with TCAS experience**. If you are not qualified as a current pilot with TCAS experience, we thank you for your time and interest, but please do not complete this study. TCAS experience is requested because we are interested in how pilots with this experience will transition to new types of traffic displays. *Instead, you may submit your comments on this research to: flightsym@dot.gov*.

Please do not use the Back button or navigate away from the site during your session.

Participation in the study is voluntary. You can end your participation at any time by leaving the site. *If you close your browser before the end of the study, you will not be able to re-enter the study where you left off, but data collected up to that point will be stored.*

Overview
The study has four main tasks. Approximate times for each task are given in parentheses.

- First you will see short videos of traffic displays and answer questions about one of the targets. (15 min)
- Second you will see more short videos of traffic displays, then try to determine which target is most likely to generate a TA in the next minute. (10 min)
- Third, you will answer questions about your operational experiences with TCAS traffic displays. (5 min)
- Finally, you will answer questions about the TCAS logic. (5 min)

We expect the study to take approximately 45 minutes to complete, with the bulk of the time spent on Tasks 1 and 2. Please allow 1 hour to do the entire study in one session, in case you are interrupted. The web site will time out if you make no input for 60 minutes.

Ground Rules
Please complete this study without consulting other pilots or referring to any material other than the information provided in this study. Also, please participate in this study only once.

Outcome
Results of this study will be considered by the FAA in developing guidance for manufacturers of traffic displays that show information obtained via Automatic-Dependent Surveillance-Broadcast (ADS-B). Information from ADS-B may eventually be integrated with TCAS traffic information onto a single traffic display. Your participation will help us provide recommendations to aid in the development of easy-to-use traffic displays.

To proceed to the Informed Consent form click on the **Next** button.

Next>Consent Form

Traffic Display Research Study

Traffic Display Research Study - US Department of Transportation (DOT) Volpe Center

This study is being conducted by the John A. Volpe National Transportation Systems Center, United States Department of Transportation (USDOT), and is being led by Dr. Michael Zuschlag. The USDOT Volpe Center is funded by the Federal Aviation Administration, Human Factors Research and Engineering Group.

Purpose of Study. Recent technological advances (e.g., ADS-B) provide a means to display traffic in the cockpit. Currently, standards and recommendations are being developed for these displays. The purpose of this study is to understand how traffic displays are used in order to aid in the development of easy-to-use traffic displays.

Procedure. There are four main tasks in the study:

1. You will see a series of short videos of traffic situations (10 to 30 seconds long) as they would appear on a traffic display. When the video ends, one aircraft will be selected, and you will rate the threat it represents and the chance you would be able to visually acquire the traffic out the window.
2. You will see a series of traffic situations as they would appear on a traffic display. Each situation includes two or more traffic aircraft, and you will identify the aircraft that represents the greatest threat.
3. Answer two short-answer questions about your experiences with the traffic display.
4. Answer eight true/false questions about the TCAS logic.

You will also be asked to fill out a background questionnaire about yourself as a pilot so we know some basic information about your flight experience. You may also provide us general input at the end of the study.

The study is estimated to take approximately 45 minutes to complete.

Discomfort and Risks. There are no known physical risks in this study other than what a participant might experience working on his/her home or office computer for 45 minutes. You should immediately report any suspected adverse effects of completing the study to Dr. Zuschlag or Dr. Chandra (see contact information below).

Benefits to You. Participation provides you an opportunity to aid in the development of recommendations for the design of cockpit displays of traffic information. These systems will be available more widely over the next few years, and they may be easier to use because of your input.

Assurances and Rights of the Participant. Your participation in this study is completely voluntary. Your participation is strictly confidential, and no individual names or identities will be recorded with any data or released in any reports. Only arbitrary numbers are used to identify pilots who provide data. The participant's computer IP address will not be recorded. You may terminate your participation in the study at any time by leaving the site. *Data provided until the point of termination will be stored and could potentially be used in the analysis.* Only individuals directly involved with the research study will have access to the data.

If you have any questions, please let us know. For further information about this study, please feel free to contact:

Michael Zuschlag or Divya Chandra
USDOT Volpe Center, 55 Broadway, Cambridge, MA 02142
Michael.Zuschlag@dot.gov (617)494-3250
Divya.Chandra@dot.gov (617)494-3882

Statement of Consent.

Please type in your name below so we have a record that you are voluntarily participating in this study. Your name is stored separately from all other data you provide.

I, [ ] , have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described.

[Submit and Proceed] [Print Consent Form]

Background Questions

Traffic Display Research Study

Background Information

Please answer the following questions to provide us with some information about your piloting background.

(* - required field)

Are you licensed and "current" by FAA standards and definitions? * ○ Yes ○ No

Total Flight Hours (approximate) [ ]

Flight Experience

- ☐ Air Transport
- ☐ Corporate
- ☐ Private
- ☐ Military

TCAS Experience

1. What Type of TCAS do you fly?

- ☐ TCAS I or TAS (no Resolution Advisories)
- ☐ TCAS II (with Resolution Advisories)

2. Rate approximately how much time you have flown with a TCAS traffic display:

○ < 500 hrs ○ 500 to 1500 hrs ○ 1500 to 5000 hrs ○ 5000 to 10,000 hrs ○ over 10,000 hrs

3. When was your last TCAS Training or your last review of TCAS training material?

○ Within the past year ○ 1 to 2 years ago ○ 2 to 3 years ago ○ More than 3 years ago

4. How many TCAS TAs have you experienced in the past year?

○ 0 to 5 ○ 6 to 10 ○ 11 to 15 ○ 15 to 20 ○ more than 20

5. How many TCAS RAs have you experienced in the past year?

○ 0 or 1 ○ 2 or 3 ○ 4 or 5 ○ 6 to 10 ○ more than 10

General

How did you hear about this study?

☐ ALPA ☐ NBAA ☐ From a pilot colleague

Other (specify) [ ]

[Proceed to Task 1 >>]

Not Licensed Pilot

Traffic Display Research Study

Thanks for Participating

Thank you for participating in this study. However, only licensed and "current" pilots are qualified to be participants.

If you have any questions regarding this requirement, please contact:

Michael Zuschlag or Divya Chandra
USDOT Volpe Center, 55 Broadway, Cambridge, MA 02142
Michael.Zuschlag@dot.gov (617)494-3250
Divya.Chandra@dot.gov (617)494-3882

Task 1: Traffic Rating

Instructions

Traffic Display Research Study

Instructions for Task 1

For each trial in this task, you will see a short video of a traffic display.

You will first see **three practice videos**.

Keep in mind:

- The video is only shown once and **cannot be replayed.**
- The traffic display has a **fixed range of 10 NM**. A 5 NM range ring is shown.
- Ownship is flying straight and level heading due north at **250 kt and 4000 feet** MSL.
- You **may** or **may not** see cautions or warnings. There is no sound.

When the video ends, the display will fade away leaving just one traffic aircraft in view. For this aircraft:

- Rate its **chance of becoming a TA** in the next 60 seconds.
- Rate the **chance of visually acquiring it** out-the-window.

Assume that you are looking for a 50-seat regional jet aircraft in daytime with **visibility unrestricted** conditions. Assume you are in the vicinity of a Class D airport.

When you are done entering your responses, click on the **Submit** button. Then click on the **Play** button to begin the next video.

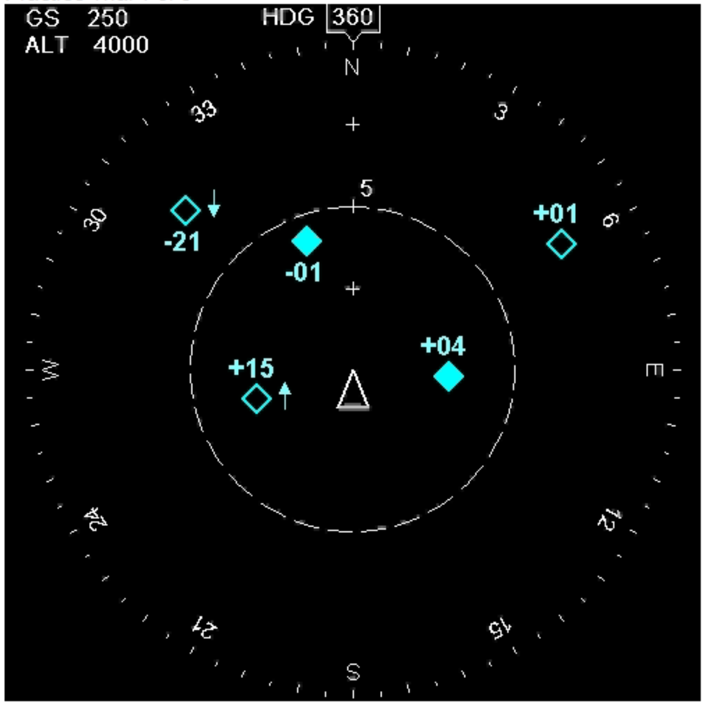
A sample traffic display is shown below. The symbols shown here are the only ones you will possibly see in the experiment. Note that the traffic display does not have all the features of a TCAS traffic display.

Begin

Practice

Traffic Display Research Study: Task 1 of 4

Practice Trial 1 of 3



What is the chance of this traffic **becoming a TA** in the next 60 seconds?

○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

What is the chance that you could quickly **visually acquire** this traffic with visibility unrestricted?

○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

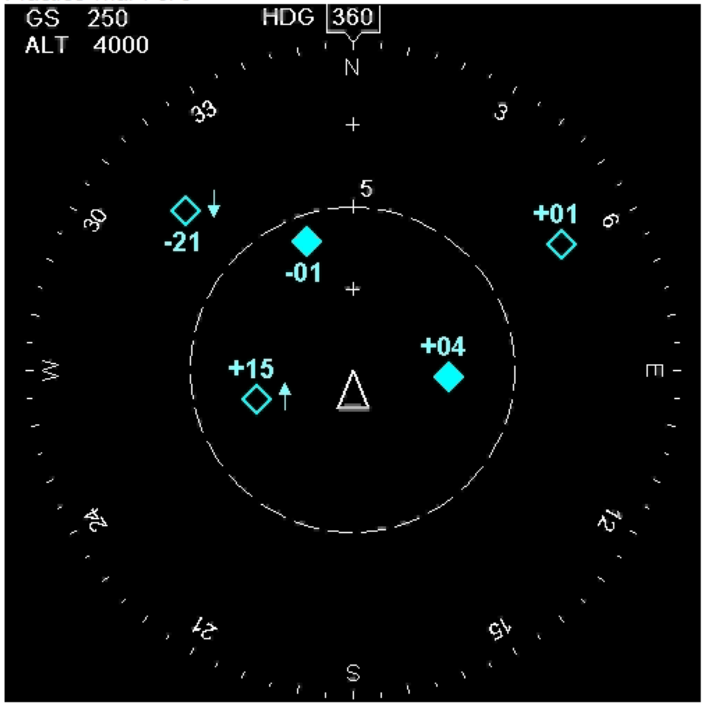
Submit

Beginning of Trial

During Video

Traffic Display Research Study: Task 1 of 4

Practice Trial 1 of 3



What is the chance of this traffic **becoming a TA** in the next 60 seconds?

○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

What is the chance that you could quickly **visually acquire** this traffic with visibility unrestricted?

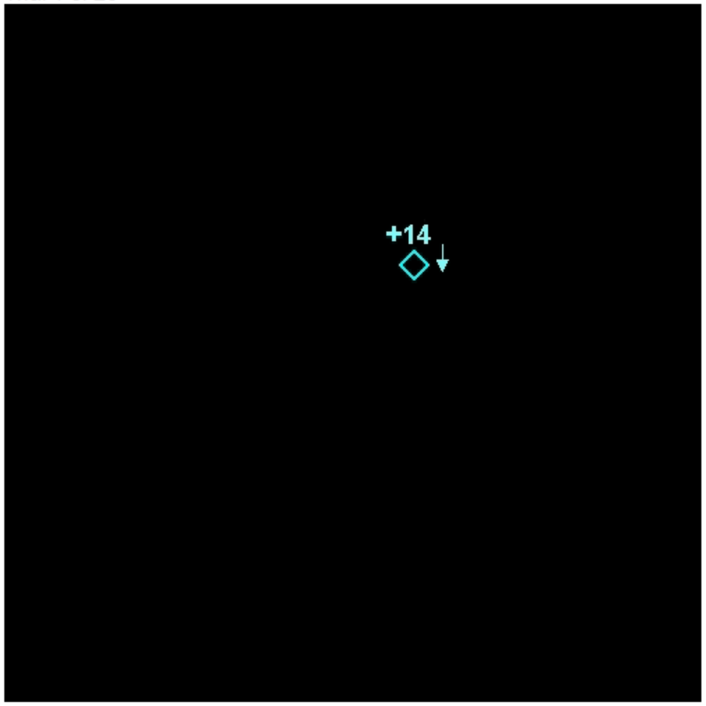
○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

Submit

End of Trial

Traffic Display Research Study: Task 1 of 4

Trial 1 of 20



What is the chance of this traffic **becoming a TA** in the next 60 seconds?

○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

What is the chance that you could quickly **visually acquire** this traffic with visibility unrestricted?

○ 0% ○ 10% ○ 20% ○ 30% ○ 40% ○ 50% ○ 60% ○ 70% ○ 80% ○ 90% ○ 100%

Submit

End of Task

Traffic Display Research Study

End of Task 1

Task 1 of 4 completed. When you are ready, please click the Next button.

Next > Task 2 Instructions

Task 2: Greatest Threat

Instructions

Traffic Display Research Study

Instructions for Task 2

This task is similar to the last one. You will again see three practice videos. Ownship is still flying straight and level heading north at 250 kt and 4000 feet MSL under the same conditions as the last task.

When the video ends the display will fade away, leaving all the aircraft on the screen, and letters will appear next to each target.

Your task is to select the letter of the aircraft that is most likely to produce a TCAS traffic advisory (TA) in the next 60 seconds. Also, rate your confidence in your selection.

When you are done entering your response, click on the **Submit** button. Then click on the **Play** button  to begin the next video.

A sample traffic display is shown below. The symbols shown here are the only ones you will possibly see in the experiment. Note that the traffic display does not have all the features of a TCAS traffic display.

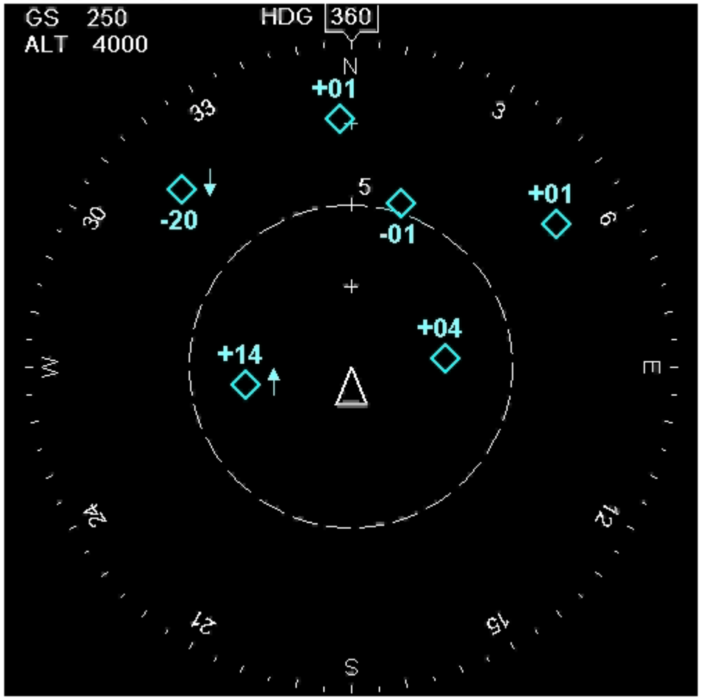
Click on the **Next** button on the bottom to start the next video.

Next

Practice

Traffic Display Research Study: Task 2 of 4

Practice Trial 1 of 3



Which aircraft is most likely to produce a TCAS traffic advisory (TA) in the next 60 seconds?

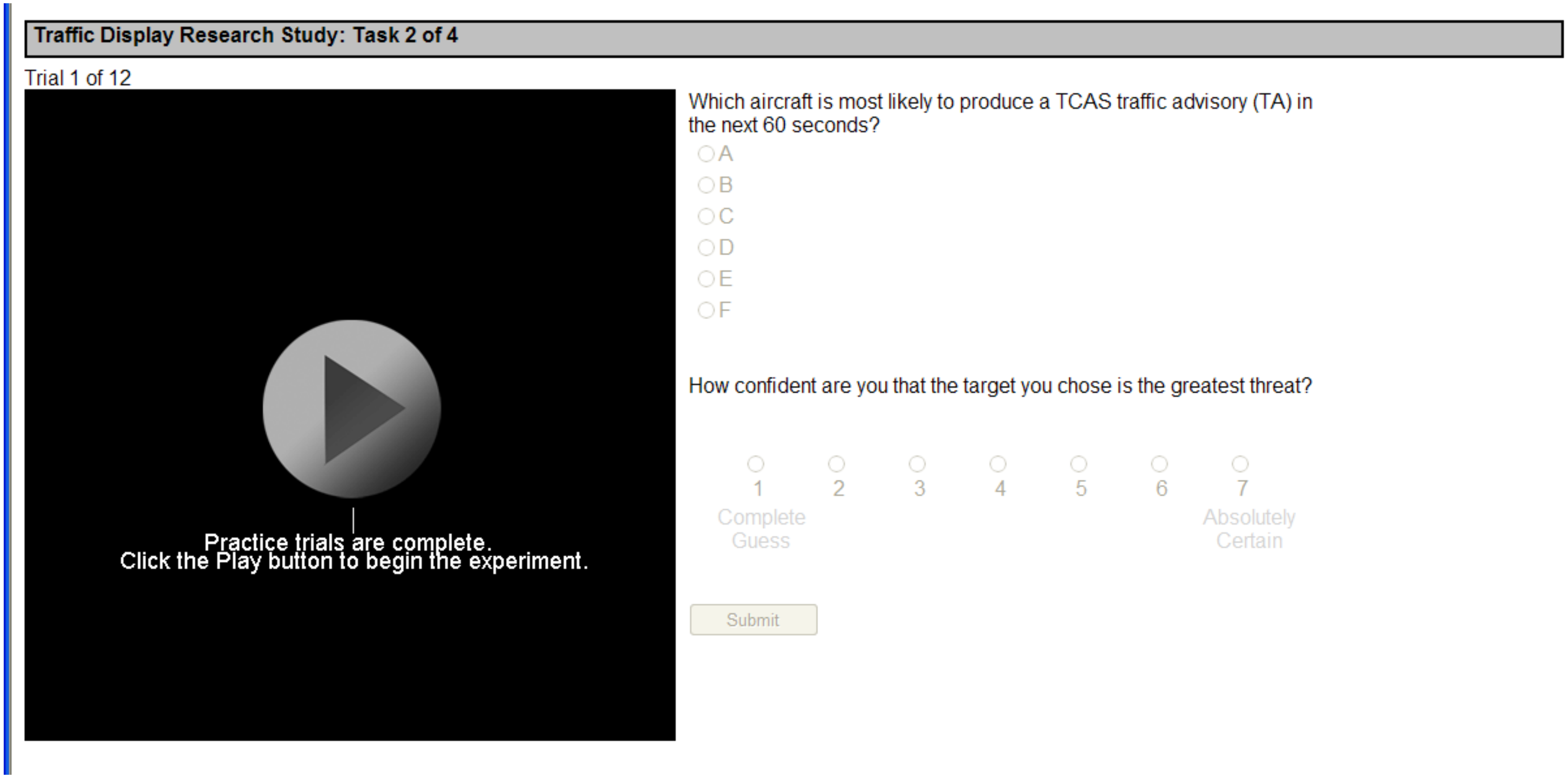
- ○ A
- ○ B
- ○ C
- ○ D
- ○ E
- ○ F

How confident are you that the target you chose is the greatest threat?

○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7
Complete Guess						Absolutely Certain

Submit

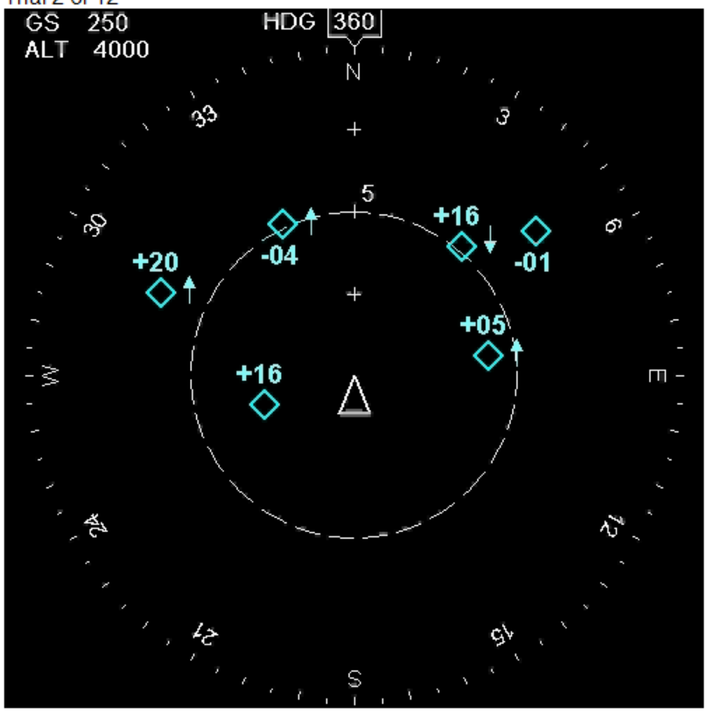
Beginning of Trial



During Video

Traffic Display Research Study: Task 2 of 4

Trial 2 of 12



Which aircraft is most likely to produce a TCAS traffic advisory (TA) in the next 60 seconds?

- ○ A
- ○ B
- ○ C
- ○ D
- ○ E
- ○ F

How confident are you that the target you chose is the greatest threat?

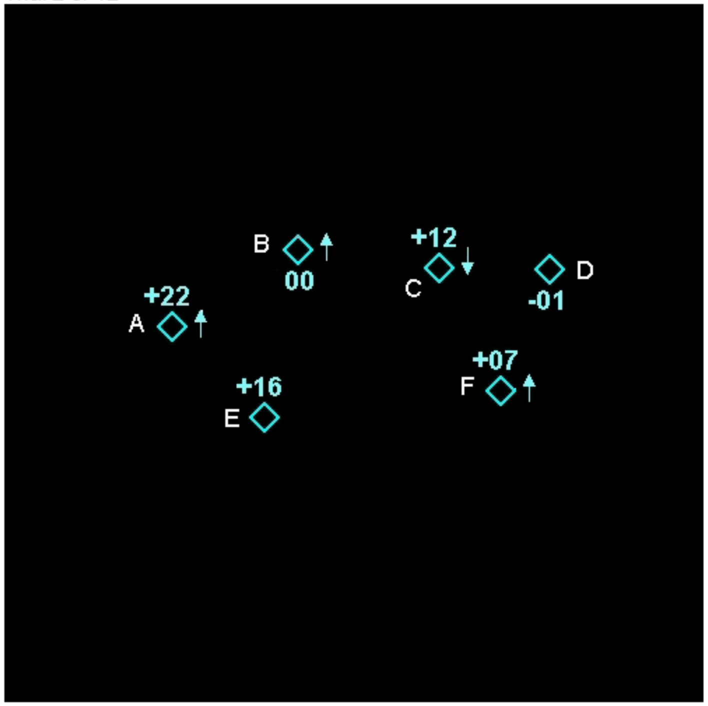
○	○	○	○	○	○	○
1	2	3	4	5	6	7
Complete Guess						Absolutely Certain

Submit

End of Trial

Traffic Display Research Study: Task 2 of 4

Trial 2 of 12



Which aircraft is most likely to produce a TCAS traffic advisory (TA) in the next 60 seconds?

- ○ A
- ○ B
- ○ C
- ○ D
- ○ E
- ○ F

How confident are you that the target you chose is the greatest threat?

○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7
Complete Guess						Absolutely Certain

[Submit]

End of Task

Traffic Display Research Study

End of Task 2

Task 2 of 4 completed. When you are ready, please click the Next button.

[Next > Task 3]

Task 3: Operational Experience

Traffic Display Research Study

Task 3 of 4

Please answer the questions below based on your **operational experience** with TCAS. There are no correct or incorrect answers.

1. Based on your **operational flight experience**, do you feel that distinguishing traffic with  and the  symbols on TCAS traffic displays is useful?

   ○ **Yes** ○ **No**

   If **yes**, please describe situations where the distinction is useful.

   If **no**, please explain further, with examples if possible.

2. Similarly, based on your **operational flight experience**, are there any situation(s) when you felt that the distinction between  and the  symbols on TCAS traffic displays caused confusion or created complications?

   ○ **Yes** ○ **No**

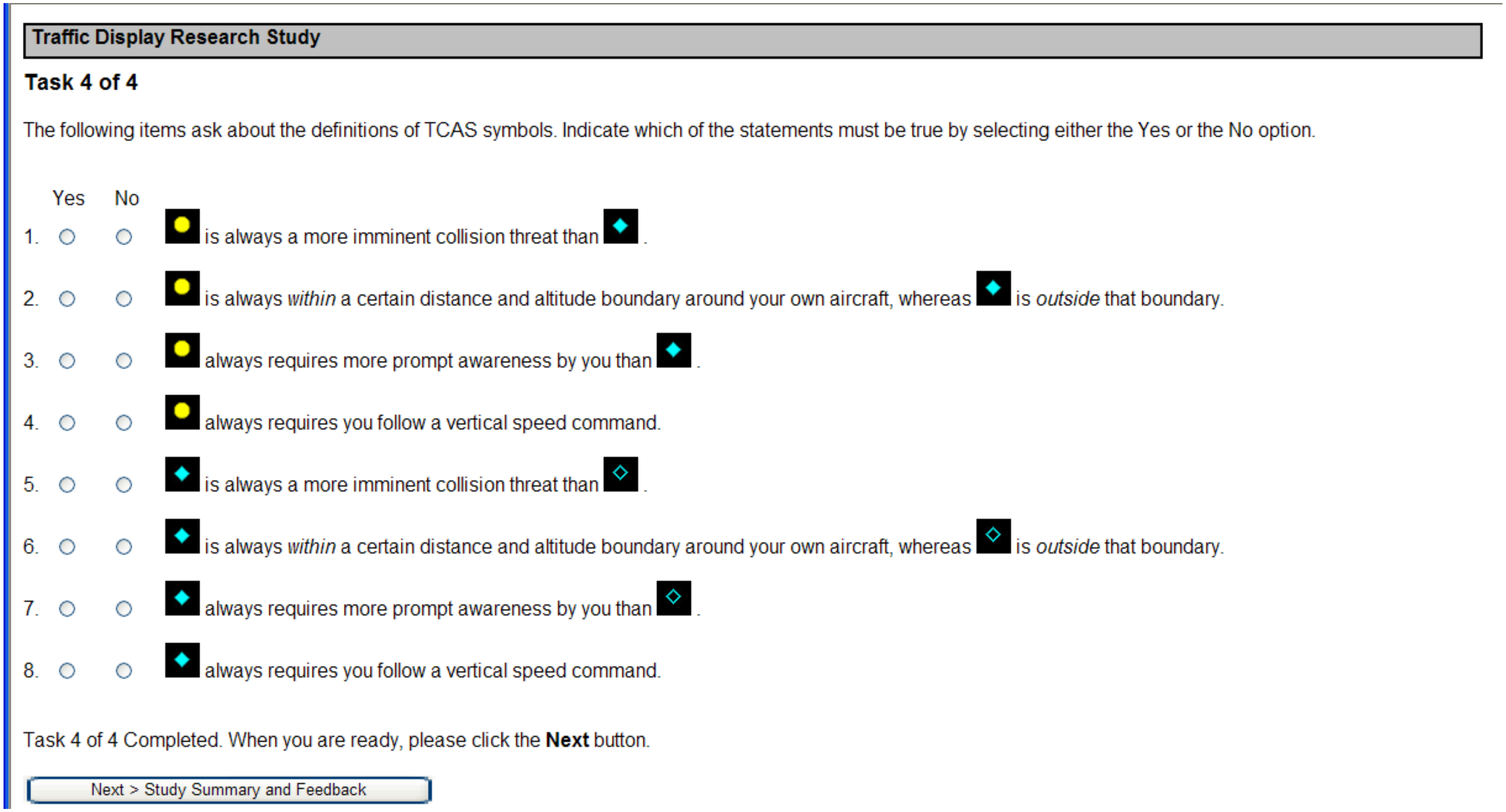
   If **yes**, please describe situations where the distinction created confusion or complications.

   What changes to the two symbols above would help to clear up the confusion or complications?

Task 3 of 4 completed. When you are ready, please click the **Next** button.

Next

Task 4: Knowledge of TCAS Symbology



Traffic Display Research Study

Task 4 of 4

The following items ask about the definitions of TCAS symbols. Indicate which of the statements must be true by selecting either the Yes or the No option.

	Yes	No	
1.	○	○	is always a more imminent collision threat than .
2.	○	○	is always *within* a certain distance and altitude boundary around your own aircraft, whereas is *outside* that boundary.
3.	○	○	always requires more prompt awareness by you than .
4.	○	○	always requires you follow a vertical speed command.
5.	○	○	is always a more imminent collision threat than .
6.	○	○	is always *within* a certain distance and altitude boundary around your own aircraft, whereas is *outside* that boundary.
7.	○	○	always requires more prompt awareness by you than .
8.	○	○	always requires you follow a vertical speed command.

Task 4 of 4 Completed. When you are ready, please click the **Next** button.

Next > Study Summary and Feedback

Final Pages

Debrief

Traffic Display Research Study

Summary of Study

Thank you for your time and input! You have completed this study on traffic displays. Your help makes it possible to develop guidelines for a set of symbols that will facilitate easier-to-use cockpit displays of traffic information for the future.

In this study, we are particularly interested in the value and potential benefit of the "proximate" status indication for the pilot (the  symbol shown on TCAS displays, as distinguished from the  symbol). The data you provided will allow us to better understand how pilots use the proximate indication as it is used operationally today.

Half of the subjects who participated saw no proximate status indication in Task 1 and Task 2. All the traffic symbols looked like  for that group. The other half of the subjects saw both the symbols used on TCAS. We plan to compare performance of the two groups to understand if the proximity indication improves pilot performance in estimating traffic threat and the chance of visual acquisition.

Thank you again for your time and effort in participating in this study.

If you are interested in preliminary results when they become available please email flightsym@dot.gov. If and when a formal report is prepared on the study, it will be posted online the USDOT Volpe Center website (www.volpe.dot.gov/hf/pubs.html).

Comments on the Study (Optional)
We are interested to know how well this study worked on your system so that we can make improvements in our survey software if needed.

Yes	No	
○	○	Was the traffic display layout and format realistic?
○	○	Were the traffic scenarios you saw realistic?
○	○	Were you able to see the videos clearly without any problems?
○	○	Were you able to complete the study in the expected amount of time?

If you answered no to any of the questions above, or if you have any other comments please enter further information below.

Thank you very much!

You may now close your browser, or click on the **End** button to save your comments and close out the study.

End

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APPENDIX B: STUDY OF NEW YORK TRAFFIC DATA

Actual airborne traffic behavior was studied to determine realistic characteristics for the traffic in the videos for the traffic rating task (Task 1). Radar track data of each aircraft were mathematically analyzed to determine:

- Ground speed as it relates to altitude.
- Vertical speed as it relates to ground speed.
- Horizontal range and vertical separation, and thus the density of traffic.

For each pair of aircraft on converging horizontal trajectories, the analysis determined the time until closest point of approach.

Key formulas for the analysis are presented in Section B.2 with detailed results in Section B.3. Section B.4 lists the boundaries of altitudes, speeds, densities, and closest point of approach that should apply to experimental tasks.

Data Source and Attributes

Traffic behavior was indicated by 2007 data tracks from the John F Kennedy airport (KJFK) surveillance radar of the New York terminal radar approach control (TRACON). Data was from around 21:00Z, which is a relatively busy time for the TRACON. The data included:

- The transponder code associated with each track.
- The north-south and east-west position of each track in nautical miles (nm) relative to the radar, with a precision of one hundredth of a mile.
- The altitude broadcasted by the transponder associated with the track to the nearest 100 feet.
- The relative time to the nearest millisecond when the track was detected by the radar.

Approximately six contiguous radar sweeps were sampled for total time of 32 seconds of traffic behavior. Aircraft operating under visual flight rules (VFR), as indicated by a transponder code of 1200 were deleted from the data. The remaining tracks were matched by transponder code to provide an initial and final position, altitude, and timestamp for 118 aircraft.

Analysis

Individual Aircraft

Aircraft distance to the radar site at John F. Kennedy Airport (KJFK) was calculated to determine its relation to altitude and ground speed. These distances were the euclidean distance from the final north-south and east-west position values as shown in Equation (4).

$$D_j = (x_{fj}^2 + y_{fj}^2)^{½} \tag{4}$$

Where:

x_{fj}, y_{fj} = Final position of aircraft j

Ground speed of each aircraft was calculated by the speed at which aircraft covered the euclidean distance between the initial and final positions, as shown in Equation (5).

$$S_j = \frac{[\,(x_{fj} - x_{ij})^2 + (y_{fj} - y_{ij})^2\,]^{1/2}}{t_{fj} - t_{ij}} \quad (5)$$

Where:

x_{ij}, y_{ij} = Initial position of aircraft *j*

x_{fj}, y_{fj} = Final position of aircraft *j*

t_{ij} = Initial time of contact of aircraft *j*

t_{fj} = Final time of contact of aircraft *j*

That is, for each aircraft, the average ground speed over the sampled time was calculated assuming a straight trajectory.

Vertical speed of each aircraft was calculated from the difference in altitude at the initial and final position, as shown in Equation (6).

$$V_j = 60 \quad \frac{a_{fj} - a_{ij}}{t_{fj} - t_{ij}} \quad (6)$$

Where:

a_{ij} = Initial altitude of aircraft *j*

a_{fj} = Final altitude of aircraft *j*

The constant 60 converted the units to feet per minute (fpm).

Time to Closest Point of Approach

The relative ranges of each aircraft *j* to every other aircraft *k* were calculated for both the initial and final positions. These initial and final ranges were calculated as the euclidean two-dimensional distance as shown respectively in Equations (7) and (8):

$$R_{ijk} = [\,(x_{ij} - x_{ik})^2 + (y_{ij} - y_{ik})^2\,]^{1/2} \quad (7)$$

$$R_{fjk} = [\,(x_{fj} - x_{fk})^2 + (y_{fj} - y_{fk})^2\,]^{1/2} \quad (8)$$

As such, these values ignored differences in altitude and represented the “flat” range between aircraft, not the slant range. These ranges were used to determine the distribution of the number of aircraft within 10 and 6 nm of each aircraft.

To calculate time to closest point of approach between each pair of aircraft, the ground speed of each aircraft was separated in to east-west (*x*) and north-south (*y*) velocity components, using Equations (9) and (10).

$$v_{xj} = \frac{x_{fj} - x_{ij}}{t_{fj} - t_{ij}} \quad (9)$$

$$v_{yj} = \frac{y_{fj} - y_{ij}}{t_{fj} - t_{ij}} \qquad (10)$$

As with ground speed, these were average velocities over the sample period. They did not represent accelerations or turns.

The relative closing velocity of any pair of aircraft was determined through the euclidean combination of the differences in the *x* and *y* velocity components, as shown in Equation (11)

$$v_{jk} = \sigma(R_{ijk}, R_{fjk})[\,(v_{xj} - v_{xk})^2 + (v_{yj} - v_{yk})^2\,]^{½} \qquad (11)$$

Where $\sigma(R_{ijk}, R_{fjk})$ was the sign function that converts speeds into one-dimensional velocities such that a negative sign indicates the two aircraft are moving apart from each other. Equation (12) defines the sign function.

$$\sigma(R_{ijk}, R_{fjk}) = \begin{cases} -1 \text{ if } R_{ijk}, > R_{fjk} \\ +1 \text{ if } R_{ijk}, \leq R_{fjk} \end{cases} \qquad (12)$$

Time to CLOSEST POINT OF APPROACH was then the final range divided by the closing velocity, after excluding aircraft pairs with negative relative closing velocities or negligible closing velocities, the latter being those less than 6 knots (Equation (13)).

$$\tau_{jk} = \frac{R_{fjk}}{v_{ij}} \text{ For } v_{ij} \geq 0.00164 \text{ nm/second} \qquad (13)$$

This was equivalent to uncapped unmodified tau in TCAS logic (FAA, 2011). Note, however, that it ignored differences in altitude.

Results

Table 9 gives the descriptive statistics for the altitudes of the aircraft. “CPA” is closest point of approach. Mean is the arithmetic average and “Std Dev” is the unbiased estimate of the population standard deviation. Kurtosis and skew represent the flatness and symmetry respectively of the data distributions. Distributions with a kurtosis between –1 and 1 have a bell-shaped distribution similar to a normal distribution. A perfect normal distribution has a kurtosis of 0. Distributions with zero skew, such as the normal distribution, are perfectly symmetrical. A positive skew indicates relatively higher frequencies of lower values than higher values, while negative skew indicates the opposite. Skewness values between –1 and 1 indicate relatively mild asymmetry.

Table 9. Descriptive statistics for traffic.

Statistic	Distance to Radar	Altitude	Ground Speed	Vertical Speed	Final Range	Time to CPA
Symbol	D_j	a_{ij}	S_j	V_j	R_{fjk}	τ_{jk}
Equation	(4)	None	(5)	(6)	(8)	(13)
Units	nm	Feet	knots	fpm	nm	seconds
Mean	31.63	11100	273	117	41.86	595
Std Dev	15.96	10000	106	1071	22.46	1014
Minimum	1.38	100*	49	–1947	0.35**	18**
Maximum	60.01	38000	502	3254	115.24	37608
Kurtosis	–1.13	0.18	–0.89	0.57	–0.10	570.47
Skew	0.05	1.04	0.11	0.94	0.60	18.83

* Two aircraft were shown with an altitude of –1000 feet and ground speed less than 10 knots. These aircraft were excluded from analyses concerning altitude and speed.

** Such low ranges and times to closest point of approach are not necessarily an alert since the aircraft may be on trajectories that miss vertically.

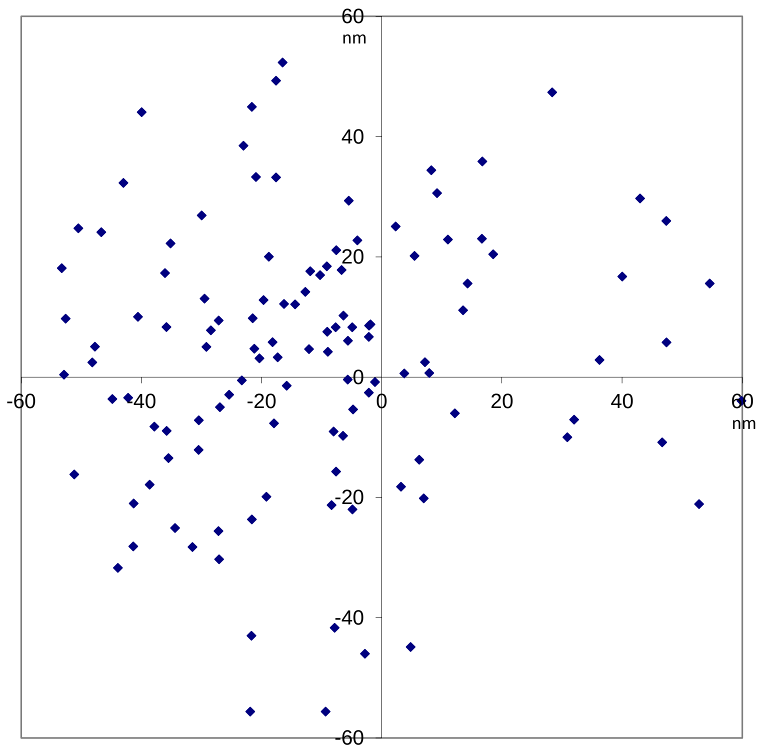

Figure 9. Final position of traffic relative to radar.

The final positions of the aircraft are shown in Figure 9. The lower right quadrant corresponds to airspace over the ocean.

Ground Speed and Altitude

Table 10 shows a correlation matrix of final distance, final altitude, and ground speed. All correlations were highly significant.

Table 10. Correlations among distance, altitude, and ground speed.

	Distance	Altitude	Ground Speed
Distance	--	0.556	0.568
Altitude	0.556	--	0.884
Ground Speed	0.568	0.884	--

Figure 10 plots ground speed and altitude, suggesting a nonlinear relation.

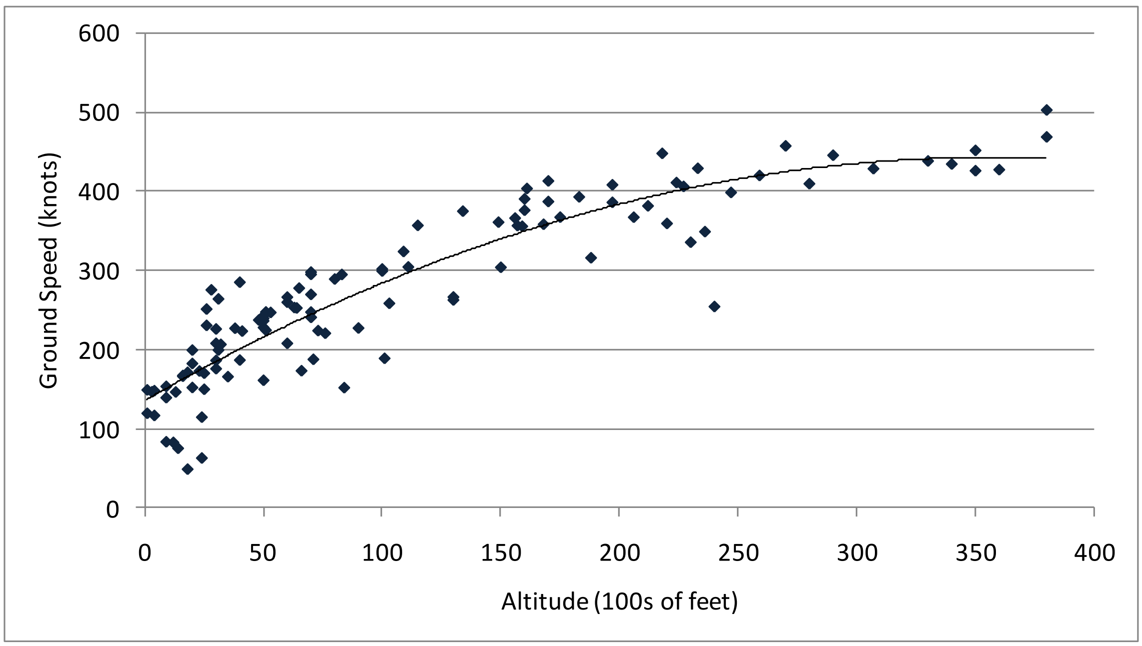

Figure 10. Ground speed as a function of altitude.

Figure 10 includes the best-fit quadratic line (R = 0.914), which is defined by Equation (14), where all coefficients were highly significant.

$$S_j' = -2.4204 \times 10^{-7} a_{fj}^2 + 0.01724\, a_{fj} + 135.5 \qquad (14)$$

When distance to radar was added to the regression, it did not yield a significant coefficient (t = 0.691, p = 0.491). The standard error of regression for Equation (14) was 43.37 knots, so 95% confidence intervals were 85 knots above and below a predicted value S_j'. For example, 95% of the aircraft at 4000 feet were predicted to have a ground speed between 115.6 and 285.6 knots. A ground speed of 250 knots corresponded to the 87th percentile[4].

[4] Because these are ground speeds rather than indicated airspeeds, it does not follow that 13% of such aircraft are violating the maximum allowed airspeed for below 10,000 feet.

Vertical Speed

Forty-two (36%) of the 116 aircraft with altitude data had the same altitude at the beginning and end of the sample for a vertical speed of 0. Figure 10 shows the distributions of the vertical speeds for all aircraft, and Table 11 provides the vertical speed statistics separately for the climbing and descending aircraft. Statistics are provided for those changing altitude at greater than 500 fpm to filter out minor altitude fluctuations.

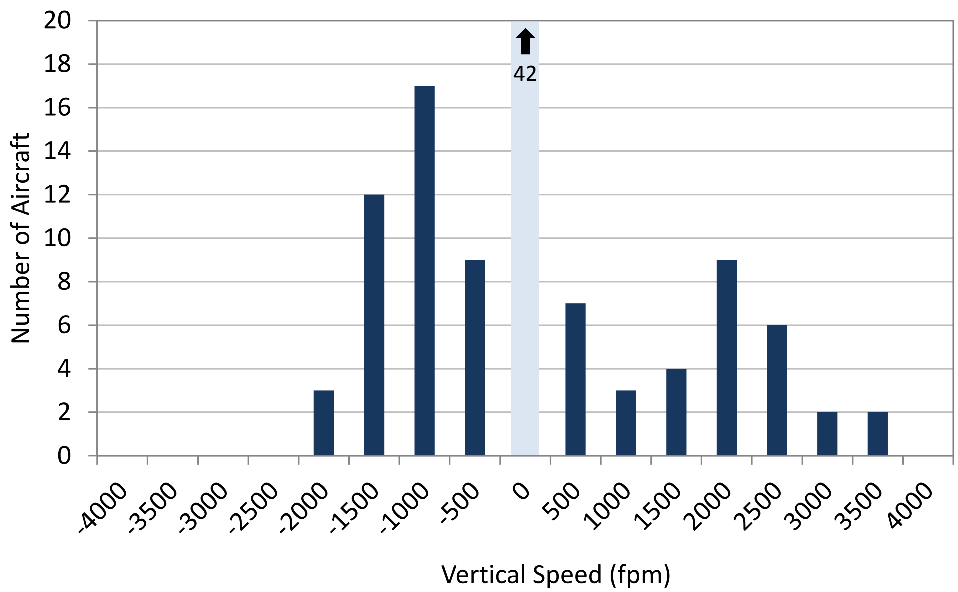

Figure 11. Distribution of vertical speeds.

Table 11. Descriptive statistics vertical speeds.

Statistic	Descending	Ascending	Descending at ≤ 500 fpm	Ascending at ≥ 500 fpm
Number	41	33	32	26
Mean	-856	1474	-1008	1796
Std Dev	405	889	314	708
95% Conf.	-62	-269	-394	408
Interval	-1649	3218	-1623	3184
Min	-1947	216	-1947	647
Max	-216	3254	-647	3254
Kurtosis	0.35	-0.92	1.70	-0.45
Skew	-0.39	0.11	-1.22	0.20

Ground speed was not significantly correlated with rate of descent ($r = 0.008$, $p = 0.961$) but was significantly related to rate of climb ($r = 0.456$, $p = 0.0070$). Figure 12 plots ground speed and climb rate.

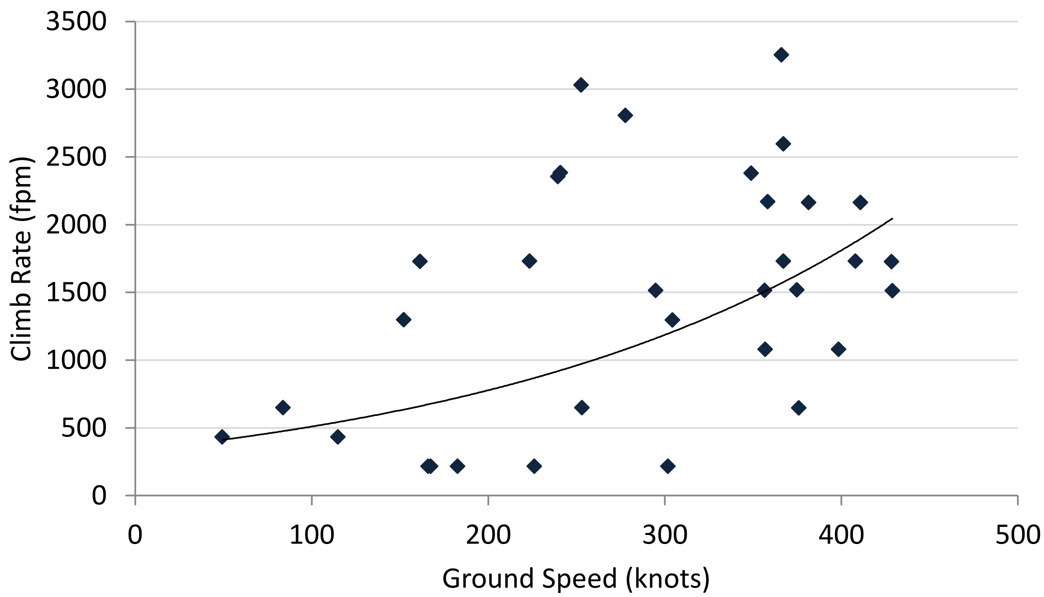

Figure 12. Climb rate as a function of ground speed.

Figure 12 also plots the best fit exponential relation (R = 0.515) as defined by Equation (15). The standard error was 821 fpm, so confidence intervals are plus or minus 1610 feet.

$$V_j' = 334.0\, e^{0.004224\, S_j} \tag{15}$$

Time to Closest Point of Approach

Figure 13 plots time to closest point of approach and final range between aircraft. The correlation between time to closest point of approach and range was 0.248, while the correlation between relative closing velocity and range was 0.196. Visual inspection found that nearly all data points were above a line described by Equation (16) and shown in Figure 13.

$$\tau_{\min\, jk} = 4.17\, R_{jk} \tag{16}$$

This line corresponds to a relative closing speed of 864 knots. This is consistent with observed ground speeds of up to 502 knots.

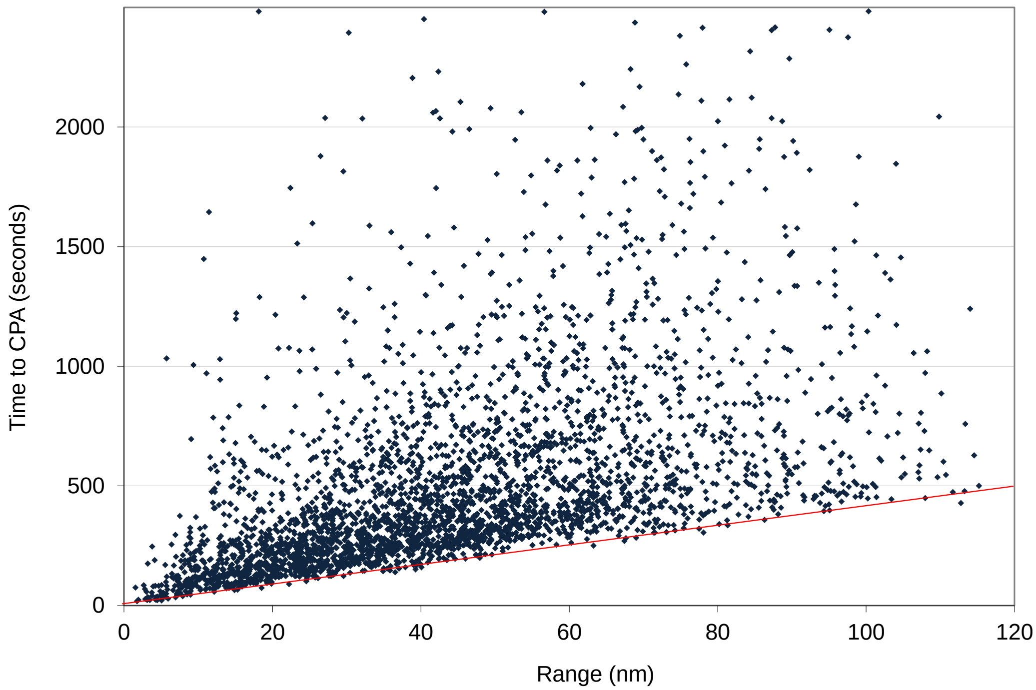

Figure 13. Time to closest point of approach as a function of range.

Traffic Density

Table 12 shows statistics for the number of other aircraft within the specified range and altitude of each aircraft. TCAS proximate traffic are aircraft within 6 nm and 1200 feet. Many TCAS implementations allow pilots to filter out traffic that is over 2700 feet above or below their own altitude.

Table 12. Statistics for number of aircraft near ownship.

Statistic	Within 10 nm and 2700 feet	Within 6 nm and 1200 feet
Mean	2.56	0.51
Std Dev	3.67	1.03
Minimum	0.00	0.00
80th percentile	5.00	1.00
Maximum	13.00	4.00
Kurtosis	0.73	3.07
Skew	1.41	2.02

Figure 14 shows the distributions of the number of nearby traffic.

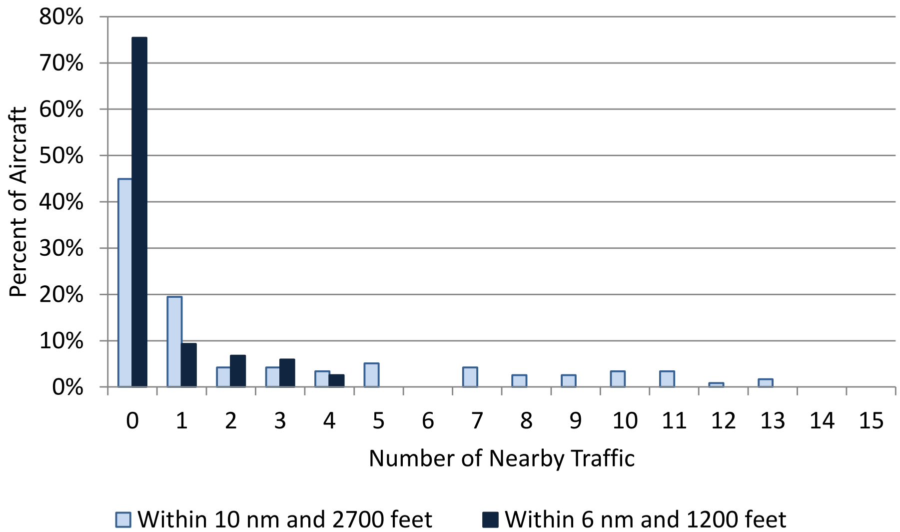

Figure 14. Percent of aircraft with each number of nearby traffic.

Forty-five percent of the aircraft had no traffic within 10 nm and 2700 feet, and 75% have no proximate traffic. On average, as aircraft got closer to the radar site at KJFK traffic density increases, altitudes get lower, and ground speeds decrease, as Table 13 shows.

Table 13. Correlations of number of nearby aircraft.

Statistic	Within 10 nm and 2700 feet	Within 6 nm and 1200 feet
Distance to radar	–0.548	–0.453
Altitude	–0.644	–0.596
Ground Speed	–0.603	–0.479

Thus, while having five aircraft within 10 nm and 2700 feet is the 80th percentile for all airspace within radar range, aircraft on approach to KJFK may nonetheless commonly encounter such densities, as their speed and altitude decrease and proximity to the airport increases.

Conclusions

Based on the analysis of airborne traffic around KJFK, the traffic rating task (Task 1) scenarios were made reasonably realistic by conforming as much as feasible to the following parameters:

- The scenarios should take place at altitudes below 11000 feet, the average observed altitude where higher traffic densities are more common.
- Ground speeds should be dependent on altitude as described by Equation (14), plus or minus 85 knots.
- Descent rates should be no more than 1650 fpm.
- Climb rates should be dependent on ground speed, as described by Equation (15), plus or minus 1610 fpm.

- The correlation of time to closest point of approach and range should be about 0.248, and the relation should be limited by the maximum ground speeds for the chosen altitudes.
- Traffic density for a low density condition may be as low one aircraft within 10 nm and 2700 feet, and zero proximate aircraft to correspond with modal densities observed.
- Traffic density for a high density condition should be about five aircraft within 10 nm and 2700 feet, and one proximate aircraft to correspond with the 80th percentile of densities observed.

APPENDIX C: DESIGN OF TRAFFIC BEHAVIOR

Traffic trajectories for the videos in the traffic rating and greatest threat experimental tasks were designed to meet the following criteria:

- Create the proper conditions for the task (i.e., various degrees of threat and potential for visual acquisition).
- Constitute a relatively representative sample of traffic encounters.
- Properly counterbalance or control for multiple variables that may affect pilot judgments.
- Achieve an appropriate level of difficulty such that the proximate status indication's potential usefulness may be exploited.
- Be consistent with actual traffic behavior, as revealed in Appendix B.

The detailed behavior of the traffic for each experimental task is provided in Section C.1and Section C.2. The behavior of distracter traffic for both tasks is detailed in Section C.3.

Task 1: Traffic Rating

Selected Characteristics and Constraints

The 20 aircraft trajectories for the traffic rating task (Task 1) included 10 proximate and 10 non-proximate trajectories. Within each set of 10, six trajectories would result in a conflict (collision), two trajectories that would miss laterally by 2 nm and two that would miss vertically by 1000 feet. In addition two of six the conflict trajectories, and both vertical miss trajectories included a change in altitude while the remaining six (four conflicts and both lateral misses) held a constant altitude equal to ownship. A range of apparent angles of motion were selected for the trajectories, but all came from the forward field of view so that ownship structure would not occlude the view of these trajectories. However, none of the trajectories were head-on to the ownship; this was done to reduce the variance of the threat judgments (Xu, Rantanen, and Wickens, 2004).

The relative closing velocities of the trajectories varied uniformly from 80 to 400 knots in 80 knot increments. The distance to the closest point of approach, not to be confused with the distance *at* the closest point of approach, varied uniformly from 1.3 to 8.6 nm. Uniform distributions were chosen to fully sample the likely range of encounters. Figure 15 shows the relation of relative closing speed to distance to closest point of approach.

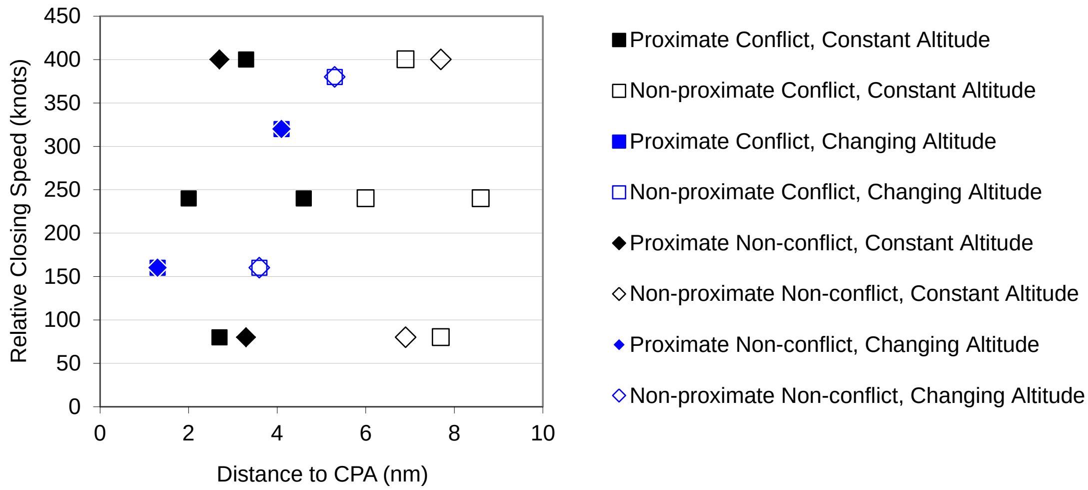

Figure 15. Traffic rating aircraft trajectories' relative closing velocities and distance to closest point of approach.

Table 14 lists the characteristics of the trajectories, including the three practice trajectories. "CPA" is closest point of approach. The intent of the practice trajectories was to expose the pilots to the range of the levels of threat and potential for visual acquisition that they would encounter in the experiment. Table 14 includes the time to closest point of approach as calculated from the relative closing speed and distance to closest point of approach. A negative horizontal miss distance indicates that the traffic would pass ownship on the left. Names for the experimental trajectories were each composed of four mnemonic letters using the following rules:

- The first letter was either and X or an O. An *X* represented a conflicting trajectory, while an *O* represented a non-conflicting trajectory.
- The second letter was either a P or an N. A *P* represented a proximate trajectory, while an *N* represented a non-proximate trajectory.
- If the third letter was a *V*, the trajectory had an altitude change and had a near or medium range to the ownship. If the third letter was *F*, *M* or *N*, the trajectory held a constant altitude; an *F* indicated a far range, *M* indicated medium range, and *N* indicated near range[5].
- The fourth letter indicates the relative closing speed. *F* indicates a fast closing speed, *M* indicates medium, and *S* indicates slow.

[5] Thus two trajectory attributes, altitude change and range, were represented by one letter rather than two. The intent of the naming was to generate a short unique identifier for each trajectory, so this collapsing of meaning was tolerated.

Table 14. Trajectory characteristics relative to ownship.

Trajectory	Distance to CPA	Relative Closing Speed	Horizontal Miss Distance	Vertical Miss Distance	Apparent Angle of Motion	Starting Relative Altitude	Time to CPA
Name	nm	knots	nm	feet	degrees	feet	seconds
Practice 1	3.3	401	0	-100	-20	-100	30
Practice 2	5.2	143	5	-100	53	-100	131
Practice 3	3.6	161	0	0	-30	1700	80
XPNM	2.0	240	0	0	-40	0	30
XPMS	2.7	80	0	0	-20	0	122
XPMF	3.3	400	0	0	20	0	30
XPFM	4.6	240	0	0	40	0	69
XNNM	6.0	240	0	0	40	0	90
XNMS	7.7	80	0	0	20	0	347
XNMF	6.9	400	0	0	-20	0	62
XNFM	8.6	240	0	0	-40	0	129
XPVS	1.3	160	0	0	-30	-1200	29
XPVF	4.1	320	0	0	30	1200	46
XNVS	3.6	160	0	0	30	1700	81
XNVF	5.3	380	0	0	-30	-1700	50
OPVS	1.3	160	0	1000	35	-200	29
OPVF	4.1	320	0	-1000	-35	200	46
OPMS	3.3	80	2	0	25	0	149
OPMF	2.7	400	-2	0	-25	0	24
ONVS	3.6	160	0	1000	-35	2700	81
ONVF	5.3	380	0	-1000	35	-2700	50
ONMS	6.9	80	-2	0	-25	0	311
ONMF	7.7	400	2	0	25	0	69

Traffic Behavior

Aircraft velocities were calculated to achieve the characteristics in Table 14 with the ownship flying due north at 250 knots (ground speed). Lateral and vertical starting positions were selected such that the aircraft would remain in the same TCAS state for the duration of the video (i.e., not transition between proximate and non-proximate, or become a TA), while maintaining realistic traffic behavior. Table 15 lists the resulting characteristics of the traffic.

Table 15. Traffic velocities and relative positions.

Trajectory	Ground Speed	Track	Vertical Speed	Starting Range to Ownship	Ending Range to Ownship	Starting Relative Altitude	Ending Relative Altitude
Name	knots	degrees	fpm	nm	nm	feet	Feet
Practice 1	186	133	0	5.2	3.3	–100	–100
Practice 2	200	325	0	7.8	7.3	–100	–100
Practice 3	137	36	–1010	4.5	3.6	1700	1363
XPNM	168	67	0	3.3	2.0	0	0
XPMS	177	9	0	3.1	2.7	0	0
XPMF	186	227	0	5.5	3.3	0	0
XPFM	168	293	0	5.9	4.6	0	0
XNNM	168	293	0	7.3	6.0	0	0
XNMS	177	351	0	8.1	7.7	0	0
XNMF	186	133	0	9.1	6.9	0	0
XNFM	168	67	0	9.9	8.6	0	0
XPVS	137	36	1462	2.2	1.3	–1200	–713
XPVF	162	260	–1089	5.9	4.1	1200	837
XNVS	137	324	–1010	4.5	3.6	1700	1363
XNVF	206	113	1453	7.4	5.3	–1700	–1216
OPVS	150	322	1462	2.2	1.3	–200	287
OPVF	184	94	–1089	5.9	4.1	200	–163
OPMS	181	349	0	4.2	3.9	0	0
OPMF	203	124	0	5.3	3.4	0	0
ONVS	150	38	–1010	4.5	3.6	2700	2363
ONVF	226	254	1453	7.4	5.3	–2700	–2216
ONMS	181	11	0	7.6	7.2	0	0
ONMF	203	236	0	10.1	8.0	0	0

Aircraft ground speed ranged from 137 to 206 knots. Tracks included aircraft both heading towards the ownship and away from ownship (being overtaken). For traffic that were changing altitude, descent rates ranged from 1010 to 1089 fpm and climb rates ranged from 1453 to 1462 fpm. Given the constraints, it was necessary that the non-conflicting proximate trajectories with altitude changes (OPVS and OPVF) pass through the ownship's altitude.

Figure 16 plots the apparent motion of the traffic (excluding practice trials) for the duration of the videos. Axes represent nautical miles. In this and other plots of the trajectories, dashed bright blue trajectories changed altitude, while black trajectories remained at ownship altitude. Open symbols represent non-proximate traffic while filled symbols represent proximate traffic. Diamond-shaped symbols represent trajectories that would miss the ownship, while squares represent traffic that conflict with the ownship.

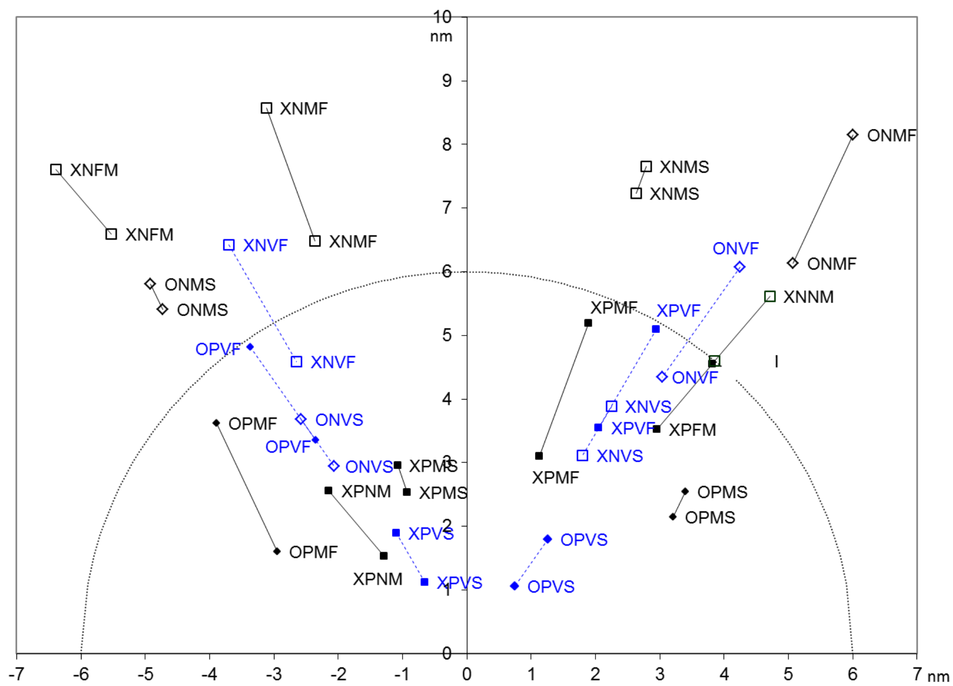

Figure 16. Traffic rating task (Task 1) trajectories relative to ownship.

Traffic Realism

Traffic for the traffic rating task (Task 1) was intended to be realistic to allow an accurate estimate of the potential of the proximate status indication to aid pilots in flight operations. Table 16 compares the behavior of the traffic in the traffic rating task with the range of actual traffic behavior as described in Appendix B. All traffic within the videos had behavior within range of actual traffic.

Table 16. Traffic rating videos versus actual traffic.

	Ground Speed Knots		Vertical Speed fpm	
Trajectory	**Video**	**New York***	**Video**	**New York****
XPNM	168	116-286	0	--
XPMS	177	116-286	0	--
XPMF	186	116-286	0	--
XPFM	168	116-286	0	--
XNNM	168	116-286	0	--
XNMS	177	116-286	0	--
XNMF	186	116-286	0	--
XNFM	168	116-286	0	--
XPVS	137	105-275	1462	< 2206
XPVF	162	128-298	–1089	> –1650
XNVS	137	136-306	–1010	> –1650
XNVF	206	97-267	1453	< 2408
OPVS	150	120-290	1462	< 2239
OPVF	184	113-283	–1089	> –1650
OPMS	181	116-286	0	--
OPMF	203	116-286	0	--
ONVS	150	150-320	–1010	> –1650
ONVF	226	80-250	1453	< 2478
ONMS	181	116-286	0	--
ONMF	203	116-286	0	--

*95% confidence interval of Equation (14) for the traffic's final altitude assuming an ownship altitude of 4000 feet.

**Either upper or lower bound of a 95% confidence interval as appropriate. Climb rates use Equation (15) to include the relation of traffic ground speeds.

Figure 17 plots the time to closest point of approach and range of the traffic. The general distribution is consistent with actual traffic as shown in Figure 13. However, the relation between range and time to closest point of approach is stronger for the video traffic, having a correlation of 0.55 rather than 0.25. As a result, proximity is a stronger and more reliable indication of threat in the videos than with actual traffic. This implies that if pilots can use the proximate status indication for threat assessments, it will appear more effective than one should expect in operations.

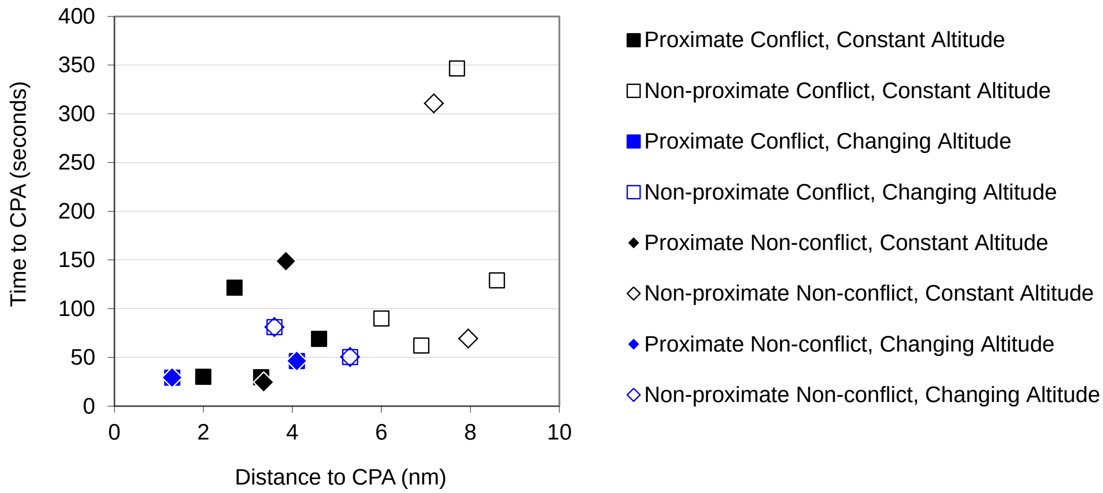

Figure 17. Time to closest point of approach as a function of range.

Theoretical Pilot Performance

Knowing the traffic trajectory characteristics, it is possible to calculate the pilot performance (R^2) that would result from various hypothetical pilot strategies for assessing threat and potential for visual acquisition of traffic. These may be compared to actual pilot performance to assess how well pilots are using the information potentially available in the traffic display (see Section 3.1).

The R^2s were calculated for following strategies.

- *Proximate Status Only*. Pilots assumed a proximate aircraft is a relatively high threat while a non-proximate aircraft is a low threat. No other information is used. This could be an easy strategy employed by pilots who saw videos with the proximate status indication: if the symbol is filled, rate the threat as high; if not, rate it as low.
- *Range Only*: Pilots only consider the distance of the aircraft to closest point of approach. In other words, pilot judge threat purely on how far the aircraft appears from the ownship on the traffic display irrespective of its closing speed.
- *Speed Only*: Pilots only consider the relative closing speed of the aircraft. In other words, pilot judge threat purely on how quickly the aircraft appear to be moving towards the ownship on the traffic display irrespective of its range.
- *Proximate Status and Speed*. Pilots weigh the proximate status and speed together to judge threat. This may result if pilots use the proximate status indication as a quick indication of range and focus attention on estimating speed.
- *Range and Speed*. Pilots weigh range and speed together to judge threat. This is somewhat different from the TCAS algorithm in that pilots combine range and speed *additively* rather than dividing the former by the latter to get time to closest point of approach, as TCAS does.

Table 17 lists the corresponding ratings of threat for each aircraft trajectory and each strategy, along with the resulting performance.

Table 17. Performance expected for various theoretical rating of threat strategies.

	Hypothetical pilot ratings of threat				
Trajectory	**Proximate Status Only**	**Range Only**	**Speed Only**	**Proximate Status and Speed**	**Range and Speed**
XPNM	7	5	5	4	2
XPMS	7	4	10	8	6
XPMF	7	1	0	0	1
XPFM	7	2	5	4	4
XNNM	3	0	5	6	6
XNMS	3	10	10	10	10
XNMF	3	6	0	2	4
XNFM	3	7	5	6	8
XPVS	7	5	7	6	3
XPVF	7	10	2	2	3
XNVS	3	6	7	8	5
XNVF	3	7	1	2	3
OPVS	7	8	7	6	3
OPVF	7	7	2	2	3
OPMS	7	5	10	8	6
OPMF	7	2	0	0	0
ONVS	3	1	7	8	5
ONVF	3	5	1	2	3
ONMS	3	4	10	10	9
ONMF	3	1	0	2	4
	Hypothetical Performance				
R^2	0.1822	0.3258	0.4368	0.5595	0.8223

Using the proximate status alone as a threat indication would result in relatively poor performance for these trajectories. However, combined use of proximity with closing speed would result in reasonably good performance –better than using range or speed alone. If the demands of the cockpit prevent pilots from fully assessing range and speed, then combining the proximate status with speed may be the next best strategy. This may be one way the proximate status could theoretically have value.

The proximate status indication also has theoretical value for assessing traffic's potential for visual acquisition. If pilots were to assume the simple strategy that proximate traffic are equally likely to be visible (e.g., all rated as 7s) while non-proximate traffic are equally *un*likely to be visible (e.g., all rated as 3s), pilot performance (R^2) would be 0.5931. Again if other tasks preclude estimating the precise range to an aircraft, then relying on the proximate status indication may be the next best strategy.

Task 2: Greatest Threat

Selected Characteristics and Constraints

The greatest threat task (Task 2) videos were constructed by pairing five proximate trajectories with five non-proximate trajectories, for a total of 10 trajectories created for the task. Each set of five included two greater-threat trajectories and three lesser-threat trajectories. Within each set of two greater-threat trajectories, one trajectory changed altitude at a constant rate, while the other maintained the same altitude as the ownship. Within each set of three lesser-threat trajectories, one changed altitude while the other two maintained the same altitude as the ownship.

In addition to complying with other design criteria (see Appendix C), greatest threat task (Task 2) traffic behaviors were adjusted such that the probability of correct identification of the aircraft with the greatest threat was approximately 75% for all videos combined (see Section 2.4). This was achieved by modifying the differences in closest point of approach and miss distances between the greater and lesser threat aircraft, then testing the videos on a sample of four pilots. All greater-threat trajectories had a time to closest point of approach of 49 seconds and zero lateral and vertical miss distances. Within the three lesser-threat trajectories, one had a time of closest point of approach of 196 seconds, one had a lateral miss distance of about 2 nm (either 10531 or 12160 feet), and one had a vertical miss distance of 1500 feet (see Table 4). The difference between lateral miss differences was due to a calculation error. These differences between greater and lesser threat aircraft were found to result in correct identification of the greatest threat traffic about 75% of the time.

Like the trajectories in the traffic rating task (Task 1), the greatest threat task (Task 2) trajectories included a range of apparent angles of motion, but none of the trajectories were head-on to the ownship. Table 18 lists the trajectory characteristics, including those of the practice trials. "CPA" is closest point of approach. The intent of the practice trials was to incrementally increase the difficulty of identifying the greatest threat as the pilot progressed from the Practice 1 trajectory pair to Practice 3. Names for the experimental trajectories were composed of the following mnemonic letters:

- The first letter indicated if the trajectory is proximate (P) or non-proximate (N).
- The second letter indicated if the trajectory is the greater threat (T) or not (N).
- The number was a serial number.

Table 18. Trajectory characteristics relative to ownship.

Trajectory	**Relative Threat**	**Distance to CPA**	**Relative Closing Speed**	**Horizontal Miss Distance**	**Vertical Miss Distance**	**Apparent Angle of Motion**	**Starting Relative Altitude**	**Time to CPA**
Name		nm	knots	nm	feet	degrees	feet	seconds
Practice 1	Greater	3.7	426	0.0	-100	17	-100	32
	Lesser	5.5	462	2.6	100	-22	100	43
Practice 2	Greater	6.0	440	0.0	100	20	100	49
	Lesser	1.9	135	0.0	-1256	11	170	51
Practice 3	Greater	4.0	293	0.0	0	40	-1200	49
	Lesser	6.0	111	0.0	-100	-35	-100	194
PT1	Greater	4.0	294	0.0	0	20	0	49
PT2	Greater	4.0	294	0.0	0	-40	-1200	49
PN1	Lesser	4.0	73	0.0	0	-35	0	196
PN2	Lesser	4.7	345	1.7	0	30	0	49
PN3	Lesser	4.0	294	0.0	1500	-25	-600	49
NT1	Greater	6.0	441	0.0	0	-20	0	49
NT2	Greater	4.0	294	0.0	0	40	1700	49
NN1	Lesser	6.0	110	0.0	0	35	0	196
NN2	Lesser	5.7	419	-2.0	0	-30	0	49
NN3	Lesser	6.0	441	0.0	-1500	25	600	49

Traffic Behavior

As with the traffic rating task (Task 1) trajectories, aircraft velocities for the greatest threat task (Task 2) trajectories were calculated to achieve the characteristics in Table 18 with the ownship flying due north at 250 knots (ground speed). Lateral and vertical starting positions were selected such that the aircraft would remain in the same TCAS state for the duration of the video (i.e., not transition between proximate and non-proximate, or become a TA), while maintaining realistic traffic behavior. Table 19 lists the resulting characteristics of the traffic.

Table 19. Traffic velocities and relative positions.

Trajectory	Ground Speed	Track	Vertical Speed	Starting Range to Ownship	Ending Range to Ownship	Starting Relative Altitude	Ending Relative Altitude
Name	knots	degrees	fpm	nm	nm	feet	feet
Practice 1	200	218	0	6.11	3.7	-100	-100
	250	135	0	8.50	6.1	111	100
Practice 2	223	223	0	8.45	5.6	100	100
	120	348	-1200	2.67	1.9	170	-230
Practice 3	191	278	1043	5.63	3.1	-1200	-852
	172	33	0	6.61	4.9	-100	-100
PT1	104	255	0	5.63	4.0	0	0
PT2	190	82	1043	5.63	4.0	-1200	-852
PN1	194	12	0	4.41	4.0	0	0
PN2	179	254	0	5.88	4.0	0	0
PN3	125	97	1826	5.63	4.0	-600	9
NT1	223	137	0	8.45	6.0	0	0
NT2	190	278	-1478	5.63	4.0	1700	1207
NN1	172	338	0	6.61	6.0	0	0
NN2	238	118	0	8.27	6.0	0	0
NN3	239	231	-1826	8.45	6.0	600	-9

Aircraft ground speed ranged from 104 to 239 knots. Tracks included aircraft both heading towards the ownship and away from ownship (being overtaken). For traffic that were changing altitude descent rates ranged from 1478 to 1826 fpm and climb rates ranged from 1043 to 1826 fpm. The lesser-threat trajectories with altitude change reached the ownship altitude by the end of the video, but would miss the ownship by 1500 feet if they were to maintain their rate of altitude change.

Figure 18 plots the apparent motion of the traffic (excluding practice trials) for the duration of the videos. Axes represent nautical miles.

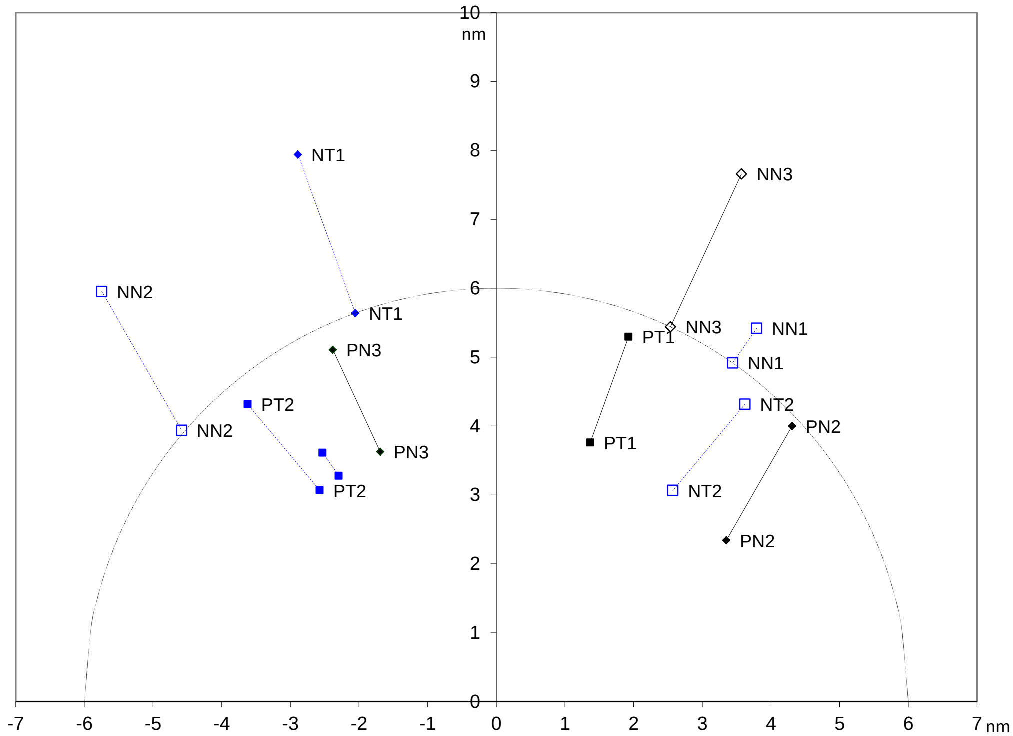

Figure 18. Greatest threat task (Task 2) trajectories relative to ownship.

Scenario Generation

Each greater-threat proximate trajectory was paired with each lesser-threat non-proximate trajectory to make six videos (2 × 3) where the proximate aircraft was the higher threat, as shown in Table 20, where each bold-text cell is one video, and "CPA" is closest point of approach. Likewise each greater-threat non-proximate trajectory was paired with each lesser-threat proximate trajectory to make six videos where the non-proximate aircraft was the higher threat. Thus, the greatest threat task (Task 2) had 12 total videos (see Table 20).

Table 20. Greatest threat task (Task 2) scenarios.

Proximate is Greater Threat		
	Greater Threat Trajectory	
Lesser Threat Trajectory	PT1 Same Altitude	PT2 Changing Altitude
NN1 - High Time to CPA	**PT1 & NN1***	**PT2 & NN1**
NN2 - Horizontal Miss	**PT1 & NN2**	**PT2 & NN2**
NN3 - Vertical Miss	**PT1 & NN3**	**PT2 & NN3**

Non-Proximate is Greater Threat		
	Greater Threat Trajectory	
Lesser Threat Trajectory	NT1 Same Altitude	NT2 Changing Altitude
PN1 - High Time to CPA	**NT1 & PN1**	**NT2 & PN1**
PN2 - Horizontal Miss	**NT1 & PN2**	**NT2 & PN2**
PN3 - Vertical Miss	**NT1 & PN3**	**NT2 & PN3**

*Cells with bold print represent a single video each composed of one lesser threat and one greater threat trajectory. There are 12 such cells, one for each the 12 trials in the task.

Distracter Traffic

Distracter traffic was additional traffic shown on displays in order to create the high density experimental conditions. The same distracter traffic was used for both the traffic rating task (Task 1) and the greatest threat task (Task 2). Distracter traffic was composed of two sets of four trajectories. Each set of four included one proximate trajectory and three non-proximate trajectories. Each set also include two trajectories with changing altitude and two with constant altitudes.

Because of time constraints in preparing the study, the realism of the parameters for the distracter trajectory behaviors were checked against pilot expert opinion, rather than the analysis of actual traffic as documented in Appendix B. Table 21 lists the trajectory behavior, including the distracters used in the practice trials. None of the trajectories maintained an altitude precisely equal to the ownship altitude, although some passed through the ownship altitude. None of the trajectories would result in a distracter passing in front of the ownship. Most trajectories within each set had generally similar tracks as might be expected of traffic converging on a limited number of approaches. Ground speeds varied from 100 to 200 knots and vertical speeds were -1000, 0, or 1000 fpm.

Table 21. Trajectory behavior.

Trajectory	Set	Ground Speed	Track	Vertical Speed	Start Relative Position X	Start Relative Position Y	Starting Relative Altitude
Name		knots	degrees	fpm	nm	nm	feet
Practice 1	-	100	165	0	2.86	0.93	400
Practice 2	-	140	160	0	6.23	5.12	100
Practice 3	-	200	90	1000	-3.61	-0.11	1317
Practice 4	-	166	160	-1000	-5.32	6.26	-1917
1P	1	200	-80	0	-2.41	0.70	-600
1N1	1	100	-85	-1000	-5.95	3.64	-17
1N2	1	140	-110	0	3.73	1.16	1400
1N3	1	100	-110	-1000	6.52	5.58	-1817
2P	2	150	135	1000	3.91	1.23	400
2N1	2	175	135	0	5.31	5.08	-100
2N2	2	100	0	0	-2.75	0.67	1600
2N3	2	125	130	1000	-6.03	3.09	1900

The names for the experimental distracter trajectories were composed of the following mnemonic characters:

- The first character represented the set number.
- The second character indicated if the trajectory is proximate (P) or non-proximate (N).
- The last character was a serial number.

Table 22 lists how traffic appeared on the traffic display given their behavior in Table 21.

Table 22. Trajectory characteristics relative to ownship.

Trajectory	Set	Apparent Angle of Motion	End Relative Position X	End Relative Position Y	End Relative Altitude	End Range to Ownship
Name		degrees	nm	nm	feet	nm
Practice 1	-	-4	3.00	-1.00	400	3.2
Practice 2	-	-7	6.50	3.00	100	7.2
Practice 3	-	-39	-2.50	-1.50	1650	2.9
Practice 4	-	-8	-5.00	4.00	-2250	6.4
1P	1	42	-3.50	-0.50	-600	3.5
1N1	1	22	-6.50	2.30	-350	6.9
1N2	1	24	3.00	-0.50	1400	3.0
1N3	1	18	6.00	4.00	-2150	7.2
2P	2	-17	4.50	-0.75	733	4.6
2N1	2	-18	6.00	3.00	-100	6.7
2N2	2	0	-2.75	-1.50	1600	3.1
2N3	2	-16	-5.50	1.25	2233	5.6

Figure 19 through Figure 21 plot the apparent motion of each set of distracters for the duration of the videos. Because of the relatively high ground speed of the ownship, all distracters moved generally from the top of the display to the bottom. That is, none of the distracters were overtaking the ownship.

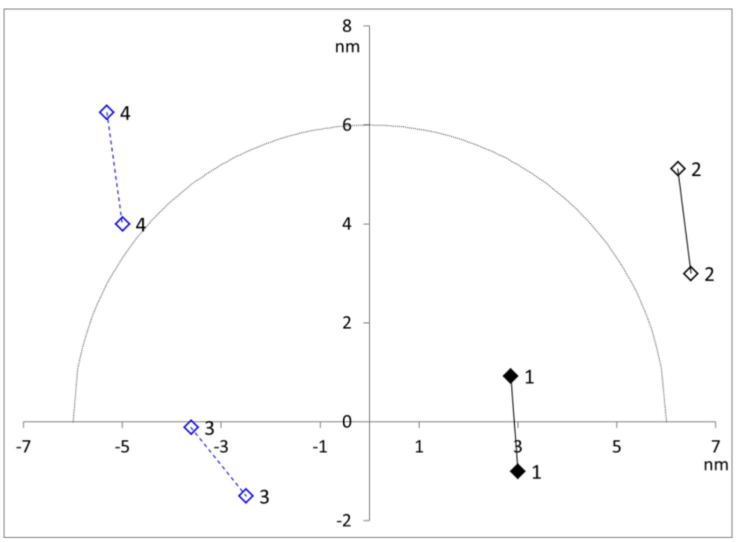

Figure 19. Trajectories of practice distracters relative to ownship.

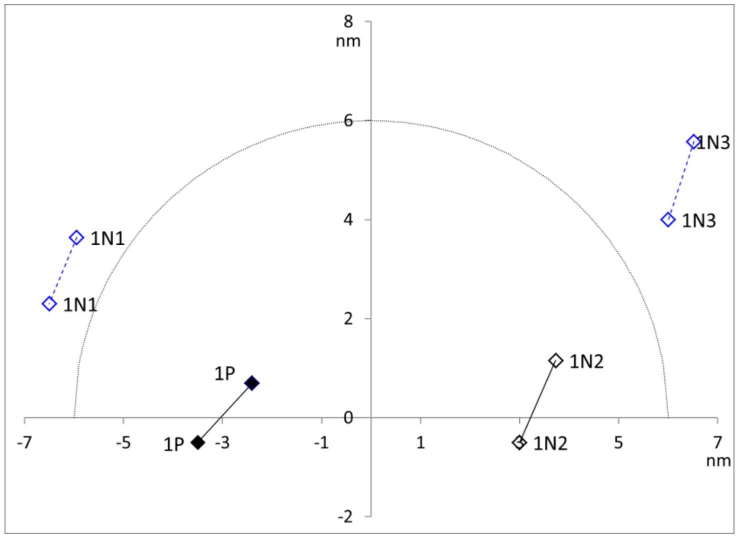

Figure 20. Distracter Set 1 trajectories relative to ownship.

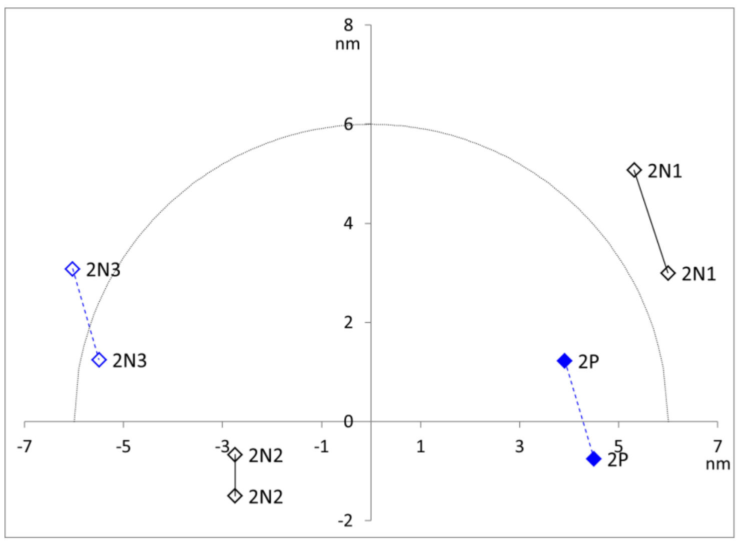

Figure 21. Distracter Set 2 trajectories relative to ownship.

The two distracter sets were matched to the trajectories as shown in Table 23 and Table 24. Each traffic rating task (Task 1) trajectory always had the same distracters. Similarly, each pair of greatest threat task (Task 2) trajectories always had the same distracters.

Table 23. Combining distracter sets with traffic rating task (Task 1) trajectories.

Trajectory	Set	Trajectory	Set	Trajectory	Set	Trajectory	Set	Trajectory	Set
XPNM	1	XNNM	1	XPVS	1	OPVS	1	ONVS	1
XPMS	2	XNMS	2	XPVF	2	OPVF	2	ONVF	2
XPMF	1	XNMF	1	XNVS	1	OPMS	1	ONMS	1
XPFM	2	XNFM	2	XNVF	2	OPMF	2	ONMF	2

Table 24. Combining distracter sets with greatest threat task (Task 2) trajectories.

Proximate Threat Source				**Non-Proximate Threat Source**			
	Non-Proximate Trajectory				Proximate Trajectory		
Proximate Trajectory	NN1	NN2	NN3	Non-proximate Trajectory	PN1	PN2	PN3
PT1	1	2	1	NT1	1	2	1
PT2	2	1	2	NT2	2	1	2

All practice trials used the same four practice distracters.

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APPENDIX D: CODING OPERATIONAL EXPERIENCE RESPONSES

Responses to the open-ended questions in the operational experience task (Task 3) were categorized and tested for inter-judge reliability. The categories were initially formed by a researcher reviewing the responses and qualitatively extracting common themes. These initial categories were then defined and refined into a formal coding scheme of six categories with three categories for the function of the proximate status indication, and three categories for the problems or improvements for the proximate status indication.

Each of the six categories was binary, where each response was classified as either yes or no for each category. Categories were applied to the pilot's entire open-ended response to the task, irrespective of the specific question answered or the pilot's selection of the forced-choice items. That is, the number of "responses" equals the number of pilots that completed the task.

The coding scheme is reproduced below. None of the categories are mutually exclusive. However, classifying a response as yes for *guides visual search* or *indicates threat* automatically meant the response was also classified as yes for the guides attention category.

Coding Scheme

Function of Proximate Status Indication

Guides Attention. Examples:

- Determines or encourages what to attend to.
- Identifies targets needing attention.
- Sorts out or separates relevant or significant targets.
- Helps prioritize targets.
- Catches pilots attention.
- Stands out more than other targets.
- Can pick up easily on traffic worth noting or watching.

Indicates Potential Threat. This also implies that proximate guides attention. Examples:

- Directs pilot towards "threats."
- Indicates a possible "problem" or "concern."
- Identifies an "intruder."
- Predicts a potential "conflict."
- Suggest target may become a "TA."
- Indicates a level of "alert" or "threat."

Guides Visual Search. This also implies that proximate guides attention. Examples:

- Encourages pilot to visually search for target.
- Helps select target to look for OTW.
- Prompts pilot to search for target.

The following types of statements received no category above.

Statements that do not specify how the proximate status is used. Examples:

- Makes it easy to read the display.
- It’s a simple or sensible distinction.
- Help with traffic awareness.
- Backup to looking OTW for traffic.
- Tells me closure rate.
- Useful to maintain separation.
- Good when display is cluttered or busy time in cockpit.
- Helpful for IMC.

Statements that do not include an operational function. Examples:

- Shows a different status.
- Distinguishes traffic from each other.
- It’s standard or familiar.
- Tell who is within 1200 ft and 6 nm.
- See who is at your attitude.

Problems and Improvements of Proximate Status Indication

Poor Threat Indication. Examples:

- Doesn’t really represent threat.
- Filled should represent a bigger threat than it actually does.

Show More Information. Examples:

- Instead of discrete levels, should gradually transition as threat increases.
- Should have velocity vector or trend lines.

Need Different Coding. Examples

- Color difference would work better.
- Use blinking symbol to get attention.
- Need to make difference more conspicuous.

Statements like the following received no category above.

- Generally not distinguish between filled or not.
- Filled or empty not of interest or otherwise not used.
- Not know difference between fill or not.
- Too difficult to interpret.
- Eliminate proximate status indication.

Reliability Evaluation

A reliability evaluation was performed to determine if the categorization scheme results in objective and consistent classification of the response independent of the judge categorizing the responses. All pilot responses were independently categorized by two researchers and compared to assess inter-judge reliability. Table 25 shows the results of these comparisons, providing the number of responses each that judge classified as in the category (columns labeled "Yes") or not in the category (columns labeled "No").

Table 25. Number of pilot responses placed in each category by each judge.

	Response Classification					
Judge 1	No	No	Yes	Yes		
Judge 2	No	Yes	No	Yes	**Agreement**	**Correlation**
Function						
Guides Attention	41	6	1	53	93%	0.864
Guides Visual Search	91	2	0	8	98%	0.885
Indicates Threat	62	5	0	34	95%	0.898
Problems and Improvements						
Poor Threat Indication	97	2	1	1	97%	0.394
Needs More Information	95	2	0	4	98%	0.808
Needs Different Coding	84	5	1	11	94%	0.763

The agreement column in Table 25 represents the percent of responses classified the same way by the two judges; that is the percent of responses with "Yes" for both judges or "No" for both judges for a given category. Inter-judge reliability was generally very high, exceeding 90% for all categories. However, the product-moment correlation among the judges, shown in the correlation column, is a better indication of inter-judge reliability since it takes into account the relative prevalence of each classification (Hayes, 1981). Based on these correlations, the inter-judge reliability is adequate for research purposes for all categories except for the poor threat indication category. Judges did not agree on three key responses, which are in Table 26.

Table 26. Responses when judges disagreed on the poor threat indication category.

Pilot	Response
A	At a quick glance, it doesn't really signify if the aircraft is a possible threat or not. Prefer a change of color.
B	It's useful because it identifies aircraft as a potential problem. It would be more useful if the identification were more reliable, but the concept is very helpful to me.
C	Traffic is traffic regardless of symbology. I have had IFR traffic vectored right into me as well as VFR traffic operating in supposedly IFR airspace.

It may be inherently difficult to determine if these responses are necessarily a criticism of the usefulness of the proximate status indication in assessing threat.

Uncategorized Responses and Potential for Alternative Responses

Open-ended responses in the operational experience task (Task 3) that do not fit in a classification scheme may represent:

- The responses that are too vague or unclear to qualify for any existing category.
- The responses that are irrelevant for the questions asked.

- The responses that represent legitimate categories not included in the coding scheme.

Of particular interest are the following conditions:

- Pilots who indicated in the force-choice questions that the proximate status indication was useful but provided no classifiable open-ended responses on the function it serves.
- Pilots who indicated in the force-choice questions that the proximate status indication can be confusing or cause problems but provided no classifiable open-ended response on problems or improvements.

The open-ended responses in these conditions may comprise legitimate categories outside the coding scheme. Such uncategorized responses are reviewed in detail here to establish the potential for categories of responses other than those explicitly identified in this study.

Eighty-four pilots indicated through the operational experience task (Task 3) forced-choice questions that the proximate status indication was useful. Of these, 58 (69%) had open-ended responses that were classified as "Yes" in at least one of the proximate status indication function categories. This leaves 26 pilots who find the proximate status operationally useful, but had responses that could not be systematically assigned to a use. Five of these 26 pilots gave no open-ended responses. Table 27 reproduces the remaining 21 responses. Except where otherwise indicated by bracketed text, the text in each response describes "a situation where the [proximate/non-proximate] distinction is useful."

One pilot (A) apparently accidentally indicated that the proximate status indication was useful. Many of the remaining pilots apparently find the proximate status indication useful in high workload or density situations (e.g., Pilots B though H). Possibly, the pilots mean they focus more on the proximate traffic when attentional resources are strained. However, these responses were not specific or clear enough to meet the coding scheme's criteria for the guides attention category. Some (Pilots I through K) might be referring to the information gained from a *change* between non-proximate to proximate—that it indicates if an aircraft is closing on the ownship, but this appears to describe at most only three pilots. The remaining 10 responses do not seem to provide sufficient content to infer the operational use of the proximate status indication. These include general use that may be applied to the entire display (Pilots M and N) and definitions of proximate (Pilots P and Q).

Nine pilots indicated through the operational experience task (Task 3) forced-choice questions that the proximate status indication could cause confusion or complications. Of these, seven (78%) had open-ended responses that were classified as "Yes" in at least one of the proximate status indication problems and improvements categories.

Of the two remaining pilots, one provided no open-ended responses. This leaves one pilot with uncategorized responses. For "Describe situations where the distinction created confusion or complications," this pilot entered that "it takes the brain a second or two to differentiate." This response may imply that the pilot believes that more distinct coding should distinguish the proximate and non-proximate traffic, but this response was not specific enough to meet the coding scheme's criteria for the need different coding category. For "describe a situation where the distinction is useful," the pilot entered "familiar with the visual display" (Pilot R in Table 27).

Table 27. Responses with uncategorized functions for proximate status indication.

Pilot*	Response
A	Never really taken in account the solid or empty symbol. I am more concerned with relative altitude, trend, and range.
B	The TCAS display is one of many things we look at with a glance. Separating proximate from other traffic helps to read the display quickly when in a high density environment.
C	High workload situations such as the traffic pattern
D	When there is a large number of targets on the display. [To improve it,] change colors, but still use the open and shaded boxes. e.g., White open box and blue shaded box. I believe the aircraft I fly these symbols are both white.
E	When multiple target aircraft are concerned . [To improve it,] maybe flashing of the highest threat traffic
F	Heavy work load.
G	In areas of lots of targets
H	In cases when a pilot is too task saturated to determine the closure rate
I	Change in status
J	Any closing situation
K	Perhaps helps with determining the closure rate
L	Easier to tell above or below
M	Helps to maintain correct separation when conducting a visual approach and following traffic. Any situation when traffic separation may be compromised.
N	When you have not visually identified the traffic.
O	Would help separate traffic from each other on the display.
P	When traffic gets within 5 miles of your aircraft 1000 feet or less.
Q	Solid diamond indicates traffic within 6 miles and +/-1200 feet
R	Familiar with the visual display. [A potential problem is that] it takes the brain a second or two to differentiate
S	Always. [To improve it,] it would be very helpful to depict the direction/trend for the aircraft.
T	Simple
U	It is logical to me.

*The same pilot identifiers in different tables are not necessarily the same pilot.

In summary, pilots did not articulate any frequent uses for the proximate status indication other than the functions categories in the coding scheme. Likewise, pilots in this study do not appear to have any clear issues with the proximate status indication other than the problems and improvements categories in the coding scheme.

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APPENDIX E: RESULTS OF DEBRIEFING QUESTIONS

The debriefing page for the study included forced-choice questions on the quality of the pilot's experience with the experiment. It also had a blank for free-form typed comments. Ninety-six pilots completed at least some of these items, with 24 providing comments. The statistics for the forced-choice questions are in Table 28.

Pilots nearly unanimously regarded the display to be realistic, including those who were in the without proximate status indication conditions for the traffic rating and greatest threat tasks (Tasks 1 and 2). If pilots noticed that the proximate status indication was missing during these tasks, they did not regard it as a major departure from realism. The one pilot who said the display was not realistic commented that, "The range on your TCAS vs the one I'm familiar with was a little different. I'm used to a 6 miles ring with a 2 mile inner ring." The traffic display in the videos had a single ring at 5 nm, consistent with navigation display design, which sometimes is used to display TCAS traffic. Another pilot commented that she or he "figured that the displays I was looking at used the wrong symbols because they were programmed incorrectly into the test," which may have referred to the lack of a proximate status indication. Nonetheless, this pilot rated the display as realistic.

Table 28. Response to forced-choice debriefing questions.

		Pilots Answers			
		Yes		No	
Topic	**Question**	#	%	#	%
Display	Was the traffic display layout and format realistic?	95	99%	1	1%
Scenarios	Were the traffic scenarios you saw realistic?	76	80%	19	20%
Video	Were you able to see the videos clearly without problems?	96	100%	0	0%
Time	Were you able to complete the study in the expected amount of time?	92	97%	3	3%

Most pilots felt the scenarios in the videos were realistic, but a fair minority did not. Of the 19 who answered that the scenarios were not realistic, 14 provided comments, representing 58% of all pilots who gave comments. Table 29 lists the comments.

Many pilots (A through E) apparently felt the frequency or intensity of the conflicts was unrealistic, although, as one pilot acknowledges, a study on threat assessment must present frequent threats to the participants. Another common concern with realism were apparently certain videos from the greatest threat task (Task 2) where two aircraft were in conflict with each other in addition to the ownship (Pilots F through I, and possible D and E too). In particular, pilots may have been referring to videos that combine NT2 and PN2 (see Figure 18). While in retrospect such "double conflicts" should have been avoided for the sake of face validity with the participants, the inherent complexity of developing the trajectories in conjunction with scheduling concerns precluded it for this study.

Pilot J noticed several ways the tasks deviated from realism, but other pilots did not mention them. Pilot K specifically challenged the notion of using the TCAS algorithm as the standard for actual threat, although he did not describe an alternative. The remaining comments cannot be tied to specific features of the videos. Other debriefing comments not associated with a perceived lack of realism (and therefore not in Table 29) concerned the technical performance of the web site, introspection into the experience of the videos, and experiences with actual TCAS functionality on the flight deck.

In summary, it seems unlikely that the pilot-recognized departures from realism could have affected the results of this study. The presence of a double-conflict in some videos, for example, would not reasonably negate any benefits a proximate status indication would provide for comparing aircraft threats.

Table 29. Comment from pilots felt the scenarios were unrealistic.

Pilot*	Comment
A	Too much traffic, not realistic.
B	Although the high number of converging, similar altitude aircraft is possible, in my experience it is not common.
C	I found that the traffic was usually way too close to be realistic. Aircraft are climbing quickly and leveling off close to you.
D	The proximity of the traffic to each other was unrealistic and it seems that when traffic approaches becoming a TA, it isn't necessarily that obvious. This has always been a fault with TCAS simulator training. In the sim you always have to be in straight and level to receive a TCAS, which is unrealistic.
E	This may be more of a testament to the proficiency of approach controllers, but rarely is the vertical separation between aircraft realistically less than 500 feet. I'd want a phone call with the supervisor if I saw repeated separations of ~100'! Furthermore, converging courses like those in the study are also seldom. I understand that for the purposes of the study these separation scenarios are necessary, but thankfully we rarely see what in reality would be a very stressful day!
F	Very rarely will one see two aircraft within 200 feet and 0.5 miles of each other converging on you unless you happen to be flying near some military airspace. Certainly not two RJs.
G	Saw a few situations where two aircraft were flying within 100-200 feet of each other, in the same direction, but making no evasive actions. While this is possible, it's not common when under positive ATC. Thank you!
H	Many of the videos left the situation ambiguous -- was the traffic going to level off at 1000' above or below me? Was the traffic going to continue its descent or climb? Some of the situations in Task 2 had two airplanes that would have been in direct conflict with each other (loss of separation at minimum), not to mention my own aircraft. In my experience (the only place I'm likely to see this kind of traffic density is within Class B airspace) this isn't particularly realistic.
I	The situation I thought was unrealistic was when two symbols were relatively close to each other and just +1 & -1 relative alt. The closest range on the TCAS display in my aircraft (E145) is a 6 mile range with a 2 mile ring. Perhaps that difference would affect my input.
J	Tend to glance at traffic display occasionally as opposed to watching it closely. Might have been better to show snapshots. Also, the unrelated traffic moved in the same direction, vs all different directions. Also the traffic never changed directions, which happens in real life.
K	In Task 2, the aircraft that would produce a TA within 60 seconds may not always be the one that presents the greatest risk.
L	The traffic moved much, much too slow for the airspeed given in the set up
M	In 12 years of flying w/ TCAS I haven't seen most of those scenarios, even flying around NY or LA.
N	All situations seemed unrealistic.

*The same pilot identifiers in different tables are not necessarily the same pilot (e.g., Pilot A in this table is not necessarily the same individual as Pilot A in Table 27).