NASA Technical Memorandum 101036

# The Traffic-Alert and Collision Avoidance System (TCAS) in the Glass Cockpit



December 1988

Proceedings of a workshop
sponsored by NASA Ames Research
Center and held at
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# The Traffic-Alert and Collision Avoidance System (TCAS) in the Glass Cockpit

Edited by
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# Abbreviations

CAA- Civil Aviation Authority

CRT- Cathode ray tube

EFIS- Electronic flight instrument system

ECAM- Electronic centralized aircraft monitoring system

EICAS- Engine indicating and crew alerting system

FAA- Federal Aviation Administration

GPWS- Ground proximity warning system

ICAO- International Civil Aviation Organization

IVSI- Instantaneous vertical speed indicator

LIP- Limited Installation Program

LRU- Line replaceable unit

MOPS- Minimum Operational Performance Standards

ND- Navigation display

PFD- Primary flight display

RA- Resolution advisory

SICAS- Secondary Surveillance Radar Improvements and Collision Avoidance Systems

TA- Traffic advisory

TCAS- Traffic-alert and collision avoidance system

# ABSTRACT

This volume contains the contributions of the participants in the NASA Ames Research Center workshop on the traffic-alert and collision avoidance system (TCAS) implementation for aircraft with cathode ray tube (CRT) or flat panel displays. To take advantage of the display capability of the advanced-technology aircraft, NASA sponsored this workshop with the intent of bringing together industry personnel, pilots, and researchers so that pertinent issues in the area could be identified.

During the 2-day workshop participants addressed a number of issues including: What is the optimum format for TCAS advisories? Where and how should maneuver advisories be presented to the crew? Should the maneuver advisories be presented on the primary flight display? Is it appropriate to have the autopilot perform the avoidance maneuver? Where and how should traffic information be presented to the crew? Should traffic information be combined with weather and navigation information? How much traffic should be shown and what ranges should be used?

Contained in this document are the concepts and suggestions produced by the workshop participants who were divided into groups. Each group was reponsible for addressing a list of questions which pertained to the implementation of the resolution advisory display and traffic display.

Following the workshop, each participant has had the opportunity to approve or disapprove every section of this report. The disapprovals have been rectified. This document represents the consensus of all the participants.

**NASA wishes to express gratitude to the representatives from the following organizations who participated in this workshop:**

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# RESOLUTION ADVISORY DISPLAY QUESTIONS

## Group 1

1. Should the maneuver advisories be presented on the primary flight display?
2. Should the same display technique be used for TCAS II climbs/descents and TCAS III turns?
3. Should the same display technique be used for TCAS and windshear or the ground-proximity warning system (GPWS)?
4. Is it appropriate to have the autopilot perform the avoidance maneuver? If yes, must this occur only with pilot consent?

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4. Should TCAS follow the voluntary guidelines for warning systems using voice only for corrective RAs?
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6. Is 100% accuracy in response direction the highest priority design goal?
7. What other human performance parameters should be used to assess display formats?

## Group 3

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2. If the TCAS RA is presented on the primary flight display, what is the optimum format for TCAS advisories?
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## Group 4

1. Should the flying pilot and the nonflying pilot have different displays; e.g., RA vs. traffic?
2. Should three-dimensional (3-D) perspective presentations such as "tunnel in the sky" be used?
3. Should the RA display be combined with the traffic display; e.g., a traffic display inside an IVSI type display, or a 3-D traffic display with a tunnel in the sky?
4. If the TCAS RA is presented on a combined RA/traffic display, what is the optimum format for TCAS Advisories?

# TRAFFIC DISPLAY QUESTIONS

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1. Should the maximum number of displayed aircraft be limited?
2. If the number is limited, should that limit be placed by the system or be pilot-selectable?
3. Changing ranges will unclutter the display, should there be other unclutter features available to the pilot for both the traffic and any other information such as weather or map?
4. What is the minimum size and viewing distance for traffic display symbols and alphanumerics?
5. What human performance parameters should be used to assess display formats?
6. How can "heads-down" time be minimized by traffic display design?

## Group 2

1. Where should traffic information be presented to the crew?
2. Should traffic information be displayed continuously?
3. Is traffic situation-awareness improved with 3-D perspective presentations?

## Group 3

1. If the traffic information is sharing a display with the weather and map, should the traffic information be combined with weather and navigation information, "time shared," or either, by pilot selection?
2. If it is combined, what should be the ownship position on the display?
3. Should the traffic display be presented track or heading-up to conform with the outside relative position of the traffic?

## Group 4

1. How many ranges should be used for the traffic display?
2. What range(s) should be used?
3. If traffic is combined with weather and map information, what ranges should be used?
4. How should the range of the traffic display be selected: automatically by altitude, by the pilot, or both automatically and by the pilot at his option?
5. Should the traffic display revert to a known range during a traffic conflict or should this be pilot-selectable in advance?

The following pages contain the conclusions reached by the workshop participants as they addressed each of the previous questions.

# RESOLUTION ADVISORY DISPLAY QUESTIONS

## Group 1

### 1. Should the maneuver advisories be presented on the primary display?

The working group arrived at the consensus that TCAS maneuver advisories should be presented on the primary flight display, but they cautioned that if the primary flight instrument was used for more than one warning system then it would be very important to present the cause of the warning to the flight crew. Some members expressed further concern against using the primary flight display as a catchall warning display (TCAS, GPWS, & Windshear) without investigating the extent to which crews would benefit from such a system (e.g., if steering commands are used on the primary display, the pilot must be told why). Of those from the audience who responded, there was complete approval of the suggestions made and concerns voiced by this group.

### 2. Should the same display technique be used for TCAS II climbs/descents and TCAS III turns?

The group concluded that is is appropriate to use the same display technique for both TCAS II and TCAS III, and the preferred method of presentation is the flight director. One member suggested that the flight director switch into the TCAS mode automatically and command bars should be used to present the message; however, as pointed out, this is a proper area to be investigated more thoroughly. All agreed that the end of a TCAS event should be presented in a clear fashion to the crew, and it was further suggested that the flight director should return the aircraft to the original flightpath after the TCAS event is over, and this was, for the most part, met with approval by other conference attendees. In the event the TCAS command is not shown on the flight director, the majority were in support of disabling the flight director during the TCAS event. It was suggested, but not approved upon that pilots could ignore the flight director presentation during the TCAS event. Most thought it too difficult for the pilot to ignore the flight director given it is so strongly emphasized in other situations.

### 3. Should the same display technique be used for TCAS and Windshear or GPWS?

After an extensive discussion, the consensus of the group was that a common display technique should be used for TCAS, GPWS, and windshear; their preferred method of presentation from an operational standpoint would be to use the flight director. The group cautioned that if a common display is used, the pilot must be presented in a clear fashion with information on what is causing the command. As a follow-up note, if Windshear is presented on the flight director, then the flight director should be considered as the display for TCAS resolution advisories.

### 4. Is it appropriate to have the autopilot perform the avoidance maneuver? If yes, must this occur only with pilot consent?

The consensus was that it would be acceptable to have the autopilot perform the maneuver; however, as was discussed, some autopilots are not capable of performing the maneuver at the proper acceleration. All agreed that the autopilot should only maneuver with pilot consent, (e.g. using the takeoff/go-around switch).

## Group 2

### 1. Should TCAS be integrated with the master caution/warning system and subject to prioritization?

The Boeing and McDonnell-Douglas representatives seemed at first to disagree about the integration of the RA. Boeing felt that all master warnings (red) should be integrated together but Douglas wants to separate warnings resulting from aircraft systems fault (engine fire, autopilot disconnect, etc.) from those resulting from outside threats (TCAS, GPWS and windshear). The Douglas argument was that the crew needs to be aware of the exact nature of any outside threat so as to be able to assess and react in a timely and correct manner. Separate annunciator lights, audio warnings and, in the case of TCAS and windshear, a message on the primary flight display (PFD) should be provided. However all new warnings would be fed via the same box. All agreed that prioritization would be necessary. Multiple concurrent voice warnings should not be permitted. The Douglas solution would enable system and outside threats to be displayed simultaneously if two (one from each) occurred together. There was concern expressed that the RA would be the most frequent red warning received (based on the latest Piedmont data). If all warnings were displayed via the master warning panel, the relatively high frequency of RAs would dilute the impact of red alerts generally, and would result in a general increase in the reaction time to red warnings. It was pointed out that in an advanced EFIS environment (B-747-400/A320 & beyond) there would be a greater ability to differentiate between different types of warnings. It was suggested that the relatively high frequency of RAs most of which would not have resulted from a genuine collision threat, would necessitate the relative priority of the RA to be downgraded. Exactly how an appropriate weighting factor would be derived is a good question. It was suggested that when experimenting with TCAS RAs on an electronic flight instrument system (EFIS) aircraft, a comparison be made between crews with and without TCAS experience on a "clockwork" or traditional flight deck. If the EFIS system is properly designed, the symbology should be self-evident to both groups, resulting in no significant crew performance difference.

### 2. Should TCAS follow the voluntary guidelines for warning systems and use red for corrective RAs, amber for preventive RAs?

These Federal Aviation Administration (FAA) guidelines state that alerts requiring immediate action (RAs requiring a change in flightpath) should be red and those simply providing information for immediate attention (preventive alerts) should be amber. All agreed that this should be the case. (Note that the United Kingdom has been pressing for this change within the International Civil Aviation Organization's (ICAO) Secondary Surveillance Radar Improvements and Collision Avoidance System (SICAS) panel for some time. The current understanding is that the FAA has now accepted this but the change will not be in place for the Limited Installation Program (LIP) and is not included in Change 6 of the Minimum Operational Performance Standards (MOPS).) It was pointed out by one participant that the lights on the IVSI denote a region to "stay out of" and therefore should be red. Yellow would indicate a region of safe operation for short durations.

### 3. Should a "go to" region be displayed along with the stay-out-of region on a corrective RA?

The presentation of the experimental evidence of the benefits of a go-to area on the IVSI of a traditional aircraft by Rob Tuttell suggests that the answer should be "yes." In an EFIS environment, guidance will be either by the flight director or flight path vector. The Civil Aviation Authority (CAA) representative expanded on Sherry Chappell's description of the Airbus Industries demonstration in Toulouse, France (fig. 1). A comment made by Alex Fisher (British Airways) who flew the Airbus system in Toulouse

suggested that it was difficult to keep the flightpath vector in exactly the right position if only the red (keep out) area is shown. In some situations the flightpath vector need only be moved by 2-3° up or down to conform with the alert. It would be much easier to place a small green rectangle adjacent to the red rectangle to show where to put the flightpath vector or flight director bar. In addition the bank steering bar would be kept inside the narrow green area to ensure that the heading is held. When TCAS III comes along, the transfer to two dimensionally displayed maneuvers will be relatively straight forward. It was suggested, but not agreed upon, that the red area could be dispensed with altogether if the green go-to area were displayed. It is suggested that the relative merits of green only and green/red be tested by Ames Research Center during their simulator trials.

### 4. Should TCAS follow the voluntary guidelines for warning systems using voice only for corrective RAs?

Previously the FAA voluntary guidelines stated that voice alerts should only be used in time-critical situations, but recently the guidelines have been revised so that voice warnings can be used in other situations. The group felt that voice warnings could be intrusive if continued too long. Participants agreed that the voice warning be repeated two or three times for an RA and twice for a traffic advisory (TA).
Dr. Simpson, Psycho-Linguistic Research Associates, pointed out that even a second repetition is distracting to the crew, and messages should be sufficiently intelligible and detectable to be understood the first time. A single-voice warning "traffic clear," indicating that the avoidance maneuver had been successful, was also suggested. The use of voice for preventive RAs would be necessary for consistency, but should only be given once or twice to be consistent with its status as a amber alert (see question 2).

The use of "smart" voice warning systems was suggested. The voice warning would be repeated after a preset time if the correct procedure had not been carried out. This agrees to some extent with the proposals made by Roy Patterson of MRC, Cambridge, England. However, if the pilot had chosen not to maneuver because of visual separation, this could be unnecessarily distracting.

Several participants felt that auditory warnings should consist of tone and voice backup; however, this was met with some opposition. There is a danger of voice messages being masked by other cockpit communications. Tones with the correct loudness and appropriate spectral composition should penetrate all background noises. Research shows that tones increase detection rates; however, the pilots responded slower to them. The use of tones and auditory warnings should be an item in NASA trials to verify these findings.

It was suggested that the audio content of TCAS RA warnings be consistent between retrofit and EFIS aircraft. There is no way that the EFIS display of RAs will look anything like the modified IVSI display of retro-fit types. The consensus was that the tape IVSI is not suitable for RAs. When converting from traditional to glass, pilots will at least have a familiar audio warning when RAs are given.

### 5. Is voice a sufficient redundancy or are two RA displays needed?

The group decided that an audio warning (voice) and two RA visual displays are needed. It is essential that both visual and auditory cues are given for a master warning alert. The RA alert and guidance data must be available to both pilots. This does not preclude dispatch with one display inoperative.

**6. Is 100% accuracy in response direction the highest priority design goal?**

The answer is definitely yes. A wrong response to an RA in the case of a coordinated escape maneuver by two TCAS-equipped aircraft could change a potential very near miss into a collision. Display formats should be optimized with the prime objective of eliminating response errors. An important part of any NASA trial will be to identify those factors which might lead to a wrong-way response. One of the United Airlines representatives suggested that the errors may result from the pilot deciding before the RA which way he is going to go (perhaps based on information on the TA display). Once his mind is made up it will take a very compelling form of display to make him react differently.

**7. What other human performance parameters should be used to assess display**

a) Response reaction: There is a natural tendency to pull rather than push (i.e. use a positive "g" maneuver)
b) Reaction bearing in mind what was seen on the TA display. Did this influence the decision to maneuver in the wrong direction?
c) Response time and time to achieve desired trajectory
d) Accuracy of response in terms of rate, g, response reversals
e) Extent of any maneuvers on receipt of preventive alerts
f) Time taken to return to cleared flight path once the conflict has been resolved
g) Speed changes during maneuver -- incorrect use of thrust levers to maintain speed
h) Extent of deviations in altitude and load factor during maneuver
i) Effect on crew coordination of maneuver
j) Workload impact (subjective)
k) Communication workload -- inter-crew and with ATC
l) Effect of fatigue -- look at end of long session
m) Reaction to maneuvers of threat aircraft
n) Reaction to RAs to reverse action (e.g., "descend" after RA to climb)
o) "heads down" time

Prior to performance measurement, the pilots must be adequately trained and fully aware of both the operation of the TCAS and of their options in using the system.

## Group 3

**1. Can RAs be adequately presented on tape IVSIs?**

While it may be adequate to present RAs on the tape alone, it is not optimum for the following reasons:

a) It would entail displaying directive information on a secondary instrument.
b) Tape IVSIs that display the entire scale would be necessary to ensure that both the green (go to) and the red (stay out of) portions of the tape are visible to the pilot.
c) The IVSI alone can only display TCAS II advisories; another instrument (e.g., heading indicator) would be necessary to present TCAS III advisories.

**2. If the TCAS RA is presented on the primary flight display, what is the optimum format for TCAS advisories?**

First, both red (stay out of) and green (go to) areas should be displayed on the IVSI. These red and green areas should be adjacent, rather than separated by black (unlit) areas. Unlit areas can and should be used to display inappropriate vertical speeds (or speeds that should not be designated as red or green), but never to separate the red and green portions of the display.

Second, an aural RA to "maintain vertical speed" should be added to "climb," "descend," and "limit vertical speed." The advisory to "maintain vertical speed" should be used when the plane is already climbing or descending and the pilot needs to maintain the present rate (of climb or descent) to comply with the RA.

Third, the RA should be presented on both the IVSI and on the flight director. Corrective ("climb" and "descend") RAs and RAs to "maintain vertical speed" would provide guidance commands to the flight director, whereas RAs that allow a wider range of vertical speeds would not; i.e., "limit vertical speed."

Fourth, the windshear alert and the GPWS should take precedence over TCAS in the flight director system; prioritization should be done at the level of the TCAS processor so that TCAS advisories are inhibited during windshear alerts and GPWS commands.

All four concepts should be tested.

**3. If the TCAS RA display is presented as part of the flight director, how will it be differentiated from the other modes of the flight director?**

TCAS RAs should be differentiated from the other modes by the flight mode annunciator, i.e., a visually displayed TCAS on the flight director display. An aural alert will already have been presented with the RA with the voice command "crossover," "climb," "descend," "limit vertical speed," or "maintain vertical speed."

A minority of the participants supported the need for a pilot enabling action to change the flight director to the TCAS mode. Certification issues must be considered.

## Group 4

**1. Should the flying pilot and the nonflying pilot have different displays, (e.g., RA versus traffic)?**

The group recommended that both pilots should have the RA annunciated to them. This also avoids the complication of having a switch to designate the flying pilot. Traffic display could be available to either or both pilots.

**2. Should three-dimensional perspective presentations such as "tunnel in sky" be used?**

The consensus from the group was that this should only be used if the tunnel in the sky happened to be the primary display format normally used in the airplane. Of the three "advanced" airplanes currently approaching the marketplace, (747-400, MD-11, & A320), none intend to use pathway in the sky. Since

pathway in the sky is much more likely to be suited to military missions, this was not recommended by the group members as a productive area of TCAS research.

**3. Should the RA display be combined with the traffic display (e.g., a traffic display inside an IVSI-type display), or a three-dimensional traffic display with a tunnel in the sky?**

The group suggested that the combined RA and TA IVSI may have some merit, but needs further study. This combination would probably only be used for older aircraft where substitution of the existing IVSI LRU is an option. In advanced airplanes, where more options are available, integration of RA and TA is not recommended. Tunnel in the sky is not well-suited for TAs because traffic can't be seen anywhere but in front of own aircraft.

**4. If TCAS RA is presented on a combined RA/traffic display, what is the optimum format for TCAS Advisories?**

The consensus of the group was that the TA and RA should not be combined.

## TRAFFIC DISPLAY QUESTIONS

<u>Group 1</u>

**1. Should the maximum number of displayed aircraft be limited?**

As a whole, the group felt that the maximum number of displayed traffic should not be limited by the display system.

**2. If the number is limited, should that limit be placed by the system or pilot**

The system should display all of the traffic advisories (TAs), and the pilot in turn should be able to select limits for the traffic advisory display.

**3. Changing ranges will "declutter" the display. Should there be other declutter features available to the pilot for both the traffic and any other information such as weather or map?**

Where the display is size limited, the system could impose a limit; however, in no case shall the system or pilot restrict the display of threatening traffic.

**4. What is the minimum size and viewing distance for traffic display symbols and alphanumerics?**

The group consensus was that the minimum size for the traffic display symbols and alphanumerics is display dependent. The EFIS guidelines should be followed.

**5. What human performance parameters would be used to assess display formats?**

Pattern recognition, ability to visually acquire traffic, ability to discriminate between conflict and other traffic.

### 6. How can heads-down time be minimized by traffic display design?

The group did not feel that heads-down time is in and of itself a problem as long as it is used for better situation awareness.

## Group 2

### 1. Where should traffic information be presented to the crew?

The group decided that traffic information should not be forced onto either of the primary displays (PFD) and navigational display (ND). It is important not to replace vital flight data on these displays without pilot control. A suggestion by the CAA representative that the traffic information could be overlaid on the ND, even if the ND and TCAS scales were different, was rejected by Boeing and McDonnell-Douglas. The group felt that traffic information should be displayed in a position where both pilots could see it but should be in the secondary viewing area defined as between 15 and 30° of the line of sight. This effectively puts it on one of the displays in the center panel. For the new large 8 X 8 inch displays half the display may be adequate (good test for Ames Research Center). Alternatively it could replace information on the electronic centralized aircraft monitoring system (EICAM)/engine-indicating and crew-alerting system (EICAS) for the period required. It could be switchable to the ND on pilot request. In response to this group's suggestions, a number of persons expressed support for presenting traffic information on a navigation display. It was pointed out that the integration of navigation, weather and traffic information would be useful to the pilot. For further discussion on this issue, refer to Group 3's discussion of question one on traffic display.

### 2. Should traffic information be displayed continuously?

There was considerable discussion on this item, but much emphasis was initially concentrated in the use of the traffic display for general traffic awareness and even trailing and status keeping. The CAA representative was very concerned that such ideas be discussed, given the current status of TCAS. He pointed out that the display was only designed to give traffic information following a traffic alert or resolution alert and should only be used to aid visual acquisition of the threat aircraft. However it was recognized that United Airlines has specified the ability to display continuously the traffic in a given area as part of the LIP. It was also admitted by those group members who flew heavy transports that despite briefings, training, and warnings, the traffic display would be used for traffic awareness and even for horizontal maneuvers (as discovered by the last Ames Research Center simulator trials). It was finally agreed that for pure TCAS purposes, continuous display of traffic was not necessary, but could be a customer option.

The effect of continuous traffic information on heads-down time and cockpit procedures needs to be further addressed.

### 3. Is traffic situation-awareness improved with three-dimensional perspective presentations?

The group felt that their only information on which to base their answers was Steve Ellis's presentation. The unanimous answer was "probably," but more research was required and Ames Research Center has the necessary expertise to carry out such research.

## Group 3

**1. If the traffic information is sharing a display with the weather and map, should the traffic information be combined with weather and navigation information, "time shared," or both by pilot selection?**

The consensus of the group was that this question is too important not to be answered empirically. Nonetheless, we were willing to give our "best guess."

Traffic information should have the potential to be combined with weather and navigation information by pilot selection. If, under some circumstances, it is not possible to combine TCAS, weather and map information on the navigation display, then the combination of TCAS and map information is preferred. (if none of this is possible, then TCAS should at least be combined with weather radar). It was noted that, while this is a great deal of information to present on the same display, the pilot flying and pilot not flying would probably select different displays. To make the first suggestion feasible, at least two reduced ranges on the ND would be needed for the traffic advisory displays. A pilot selectable unclutter option for the traffic display would also be needed so that the display could show either: a) all traffic or b) traffic that generates either a traffic alert or advisory and proximate traffic. Proximate traffic is defined as all traffic within 6 n. mi. and within 1200 ft vertical separation. (Note that this suggestion was based on the group's educated guess that the latter display would result in no more than three aircraft on the display at any given time.)

**2. If it is combined, what should be the ownship position on the display?**

The position of the ownship needs to be consistent with the task at hand and with the mode of the display. Under some conditions (e.g., when weather information is crucial) ownship should be displayed at the bottom (center) of the display, so that none of the weather information is deleted. When weather is not a crucial factor, but traffic is, then an ownship position at two-thirds of the way down on the screen would be preferred, particularly when the traffic is behind ownship. Finally, it was noted that special provisions need to be made for answering TCAS display questions when special modes (e.g., "plan" mode) are used in flight.

**3. Should the traffic display be presented track- or heading-up to conform with the outside relative position of traffic?**

The traffic information should be presented heading up for many reasons, including the fact that it correlates with clock position and the way that the pilot is used to looking for traffic), and it further helps the pilot identify aircraft when looking out the window. If the underlying information is track-up (e.g., on the navigation display) there was no agreement reached as to whether the traffic information should agree with the ground-referenced navigation information (track-up) or the aircraft-referenced clock position information (heading-up).

## Group 4

### 1. How many ranges should be used for the traffic display?

Ross Beins of United Airlines, who has recent experience with TCAS on the DC-8 LIP airplane, suggests three range selections including 5-, 10-, and 20-mi. ranges. A standard-size range ring (3 mi.?) on the display should be used. Additional range rings would be useful for the 10- and 20-mi. ranges.

### 2. What range(s) should be used?

The consensus was that 5-, 10-, and 20-mi. ranges should be used. If TCAS surveillance is extended beyond the current 16 mi., the maximum range of surveillance should be available. It was also pointed out that the ranges should be consistent from one installation to another.

### 3. If traffic is combined with weather and map information, what range should be used?

The group and the responding attendees disapproved of automatic range changes on a TCAS display shared with map or weather. The range for traffic on these displays should be the same as selected by the pilot.

### 4. How should the range of the traffic display be selected; automatically by altitude, by the pilot, or both automatically and by the pilot at his option?

If traffic is shown on a dedicated full-time display, automatic range change as a function may be permissible as a pilot selection. Sandy Hart reported some evaluations done at Ames Research Center which indicated that pilots preferred a continual range change as a function of altitude for traffic displays. If navigation and/or weather are combined with the traffic information, the range should be fixed, as selected by the pilot.

### 5. Should the traffic display revert to a known range during a traffic conflict or should this be pilot selectable in advance?

The feeling among the pilots was that an automatic range change because of a TA would be undesirable on a map or weather radar display. On a dedicated TCAS traffic display, an automatic range change may be necessary to assure that the threat is not off scale.

## CONCLUSIONS

All of the groups identified key concepts which will require empirical testing. NASA will select the issues from this list which will yield the greatest contribution and evaluate these concepts in part-task simulation studies. From the findings of those studies, an evaluation of the TCAS displays in the Advanced Concepts Simulator will validate pilot performance in a full-mission context. Recommendations will then be made to the organizations responsible for aircraft display standards.

## REFERENCES

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16. Abstract

This volume contains the contributions of the participants in the NASA Ames Research Center workshop on the traffic-alert and collision avoidance system (TCAS) implementation for aircraft with cathode ray tube (CRT) or flat panel displays. To take advantage of the display capability of the advanced-technology aircraft, NASA sponsored this workshop with the intent of bringing together industry personnel, pilots, and researchers so that pertinent issues in the area could be identified.

During the 2-day workshop participants addressed a number of issues including: What is the optimum format for TCAS advisories? Where and how should maneuver advisories be presented to the crew? Should the maneuver advisories be presented on the primary flight display? Is it appropriate to have the autopilot perform the avoidance maneuver? Where and how should traffic information be presented to the crew? Should traffic information be combined with weather and navigation information? How much traffic should be shown and what ranges should be used?

Contained in this document are the concepts and suggestions produced by the workshop participants who were divided into groups. Each group was responsible for addressing a list of questions which pertained to the implementation of the resolution advisory display and traffic display.

Following the workshop, each participant has had the opportunity to approve or disapprove every section of this report. The disapprovals have been rectified. This document represents the consensus of all the participants.

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