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Pilots' use of a traffic alert and collision-avoidance system (TCAS 2) in simulated air carrier operations. Volume 2: Appendices

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Pilots' Use of a Traffic Alert and Collision-Avoidance System (TCAS II) in Simulated Air Carrier Operations

Volume II: Appendices

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PILOTS' USE OF A TRAFFIC ALERT AND COLLISION-AVOIDANCE SYSTEM (TCAS II) IN SIMULATED AIR CARRIER OPERATIONS

Volume II: Appendices

SUMMARY

This report describes a study of pilots' use of and responses to a traffic alert and collision-avoidance system (TCAS II) in simulated air carrier line operations.

Three levels of information regarding the location of other air traffic were presented to different groups of airline pilots current in the Boeing 727 aircraft during their execution of eight simulated air carrier flights. Traffic conflicts were generated at intervals during the flights; where appropriate, these conflicts were visible to the flight crews. Two of these levels represent the approaches taken by several airlines which have installed the collision avoidance system for an in-service evaluation. In a fourth condition, pilots flying without TCAS II equipment were exposed to the same traffic conflicts.

To ensure safe separation from conflicting aircraft, TCAS II commands a climb, a descent, or a reduction in rate of climb or descent. Aircraft separation was effective when the system was in use; no aircraft came within 200 ft vertically and 1000 ft horizontally.

Average response times did not differ as a result of the amount of traffic information available. Response accuracy, as measured by the root mean square overshoot in rate of climb or descent, also showed no differences associated with the level of traffic information. Average peak overshoots in response varied significantly among conditions: the mean for those crews with no traffic information was 2272 ft/min greater than commanded rate of climb or descent, those with traffic presented only during a conflict had a mean of 1221 ft/min, and those with continuous traffic information averaged 1317 ft/min. These momentary peak overshoot differences, however, did not result in significant differences in the amount of altitude change.

No learning effects were observed. Differences in flight experience did not appear to contribute to the small observed performance differences.

Pilots who had displays of conflicting traffic were observed to use the displays to maneuver to avoid unseen traffic prior to the issuance of a resolution advisory by the TCAS II equipment.

While the results of this experiment represent only pilot response on initial exposure to this traffic alert and collision-avoidance system under simulated conditions, they indicate that pilots are able to utilize TCAS II effectively within the response times allocated by the TCAS II logic. They also suggest that TCAS II, properly used, is effective in ameliorating the severity of the simulated traffic conflicts presented in this study.

Volume II of the report contains appendices referenced in Volume I. The appendices provide details of the experiment and the results, and contain the text of two reports written in support of the program.

Appendix A1: TCAS EXPERIMENT: HANDBOOK FOR AIR CARRIERS AND FLIGHT CREWS

Note: Appendix A1 contains material sent to participating air carriers for their information and that of flight crews designated to participate in the experiment as subjects. Appendix A2 was sent to the carriers, who constructed flight plans and dispatch papers in their own formats.

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TCAS INFORMATION TRANSFER: HANDBOOK FOR AIR CARRIER FLIGHT CREWS

Aerospace Human Factors Research Division
Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035

INTRODUCTION

This handbook describes an experiment to be conducted in the NASA-Ames Man-Vehicle Systems Research Facility by NASA and FAA personnel. The experiment is designed to evaluate the use of various Traffic Alerting and Collision Avoidance (TCAS) information presentations by airline flight crews flying routine short-haul high-density operations.

The information herein is published for the sole use of participating air carriers and flight crew members, and is not to be disseminated elsewhere to avoid compromising the design and content of the experiment scenarios.

BACKGROUND

Many years of development by the FAA and its contractors have resulted in a carefully-tested system that provides pilots in flight with data concerning traffic conflicts. This system is called TCAS. It provides information concerning potential conflicts as well as commands to assist flight crews to mitigate actual conflicts. In its present form, it provides resolution advisories only in the vertical mode; that is, pilots are commanded to climb or descend when a serious conflict is detected. The flight crew is also notified when the conflict has been resolved, in order to minimize the flight path deviation necessary to avoid a collision.

TCAS is not designed to supplant either air traffic control's system of separation assurance or the time-honored "see and avoid" system of traffic separation. Rather, it provides an independent backup to these systems, since it makes use solely of airborne transponders as its data source.

Several display formats have been proposed to provide TCAS information in the cockpit. Our task is to evaluate several such presentations on a comparative basis, with the hope that we shall be able to assist the aviation community to decide upon the information elements which should be included in the system when it becomes operational.

Our task in this experiment is to observe how flight crews respond to other air traffic when they are given information about it in various forms. To do this, we must observe a substantial number of flight crews flying simulated normal missions under precisely controlled circumstances.

**: The experiment is being conducted by personnel of the NASA-Ames Research Center's Aerospace Human Factors Research Division and the FAA's Engineering Research and Development Office at Ames Research Center.

APPROACH

Sixteen flight crews from various air carriers will come to Ames to participate in this experiment. Four crews will serve as control subjects; they will fly the routes without TCAS. The other crews will be observed while using one of three TCAS display systems. On their first afternoon at Ames, they will be introduced to our Boeing 727 simulator and ATC environment, then trained in the use of the TCAS system with which they will be equipped.

All pilots will report to the Facility on the following morning and will fly a series of eight short flights between San Francisco, Stockton, Sacramento and Los Angeles (see attached schedules). The flights will be conducted over a period of about 9-1/2 hours. They will be flown under IFR rules using Part 121 procedures. ATC will handle the flights as normal air carrier operations, utilizing the rules provided for the conduct of such flights. The air traffic control environment contains enroute and terminal sectors configured approximately as in the actual ATC environment.

Other traffic will occur as it might in the real world. ATC controllers will be in contact with some of this traffic; other aircraft flying with Mode A or C transponders under VFR will not be in contact with ATC and some non-transponder traffic may not be visible to ATC.

The flight schedule resembles those found in short-haul flying. There will be a short break half-way through the day, during which a lunch will be provided in the pilot lounge; the simulator is also equipped with a toilet. Coffee and soft drinks will be available on board.

Flight crews will be asked to conduct the flights as they normally would on the line, using their normal company procedures, checklists, etc. They will be dispatched with paperwork that resembles that which they normally use. The flight schedules are attached; crews will be oriented to the airports and gates they will use during their training (see below). Company radio will be available on frequencies to be provided. Maintenance will also be available at San Francisco and Los Angeles; maintenance facilities are not available at Stockton or Sacramento.

AIRCRAFT

The MVSRF is equipped with a Boeing 727-232 Singer-Link simulator in Delta Air Lines configuration. It is equipped with a Block V autopilot. The MVSRF staff will review the airplane's equipment with each participating crew.

CONFIDENTIALITY

Experiment records will be kept in such a way that flight crew members will not be identifiable. Though the FAA and NASA are jointly conducting this study, it is not in any sense an evaluation of pilot proficiency and under no circumstances will the data be used for any purpose other than that set forth above. The data will be lumped for reporting purposes and neither companies nor individual flight crew members will be named in reports of the experiment.

LOGISTICS

Flight crew subjects will receive transportation to and from San Francisco from their employing air carriers. While at Ames, they will be employed by the Bionetics Corporation, a contractor to NASA-Ames; Bionetics will provide Workers' Compensation insurance and will cover necessary expenses in connection with this employment. Flight crews will be provided with an automobile, single accomodations at a motel near Ames Research Center, a per-diem to cover meals and incidental expenses, and a stipend of $10.52 per hour of time spent in the conduct of the experiment.

Flight crews will report on a Monday or Wednesday at 1400 hrs Pacific time. They will spend the remainder of the day in training. On the following morning, they will report at 0730 hrs for dispatch. Crews should plan to remain in the area overnight unless they live locally; the day will be a long one. Unless a simulator malfunction has caused an abort, crews will be free to leave on Wednesday or Friday morning.

FACILITY LOCATION

The Man-Vehicle Systems Research Facility is located in Building 257 at the NASA-Ames Research Center, Moffett Field, California, at the foot of San Francisco Bay. The facility is located within the city of Mountain View and is easily accessible from Route 101, the Bayshore Freeway, which passes both San Francisco and San Jose airports. A map is attached to this package. The Bionetics Corporation will take care of obtaining entry passes and auto decals from Ames security personnel, and will also be available to handle any problems that may arise.

EXPERIMENT STAFF

For further details, contact:

Sherry Chappell, Principal Investigator,	415-694-6909
Barry Scott, Co-principal Investigator,	415-694-6379
Charles Billings, Senior Scientist,	415-694-5718
Ranita Dalton, Bionetics, Inc.,	415-694-5118
Gail Bennet-Hiley, Bionetics, Inc.,	415-694-5118

FLIGHT SCHEDULES - NASA/FAA TCAS EXPERIMENT

(All times are Pacific Daylight or Standard time)

Crews will be assigned to fly one of the following schedules:

FLT NO.	FRM	DEP:	TO	ARR:	FLT. TIME	BLK. TIME	L/O TIME	RMKS
NASA-								
712	SFO	0830	SCK	0902	0:20	0:32	0:13	TANKER
	SCK	0815	LAX	1023	0:58	1:08	0:27	
713	LAX	1050	SMF	1200	0:59	1:10	0:15	TANKER
	SMF	1215	SFO	1252	0:27	0:37	0:38	
716	SFO	1330	SMF	1406	0:24	0:36	0:14	TANKER
	SMF	1420	LAX	1533	1:03	1:13	0:27	
715	LAX	1600	SCK	1702	0:50	1:02	0:13	TANKER
	SCK	1715	SFO	1745	0:20	0:30	--	

FLT NO.	FRM	DEP:	TO	ARR:	FLT. TIME	BLK. TIME	L/O TIME	RMKS
NASA-								
715	LAX	0830	SCK	0932	0:50	1:02	0:13	TANKER
	SCK	0945	SFO	1015	0:20	0:30	0:25	
716	SFO	1040	SMF	1116	0:24	0:36	0:14	TANKER
	SMF	1130	LAX	1243	1:03	1:13	0:37	
713	LAX	1320	SMF	1430	0:59	1:10	0:15	TANKER
	SMF	1445	SFO	1522	0:27	0:37	0:28	
712	SFO	1550	SCK	1622	0:20	0:32	0:15	TANKER
	SCK	1637	LAX	1745	0:58	1:08	--	

ELAPSED TIME: 9:15
FLIGHT TIME: 5:21
BLOCK TIME: 6:48

INFORMATION FOR PARTICIPANTS

LOCAL TRANSPORTATION

Bionetics, Inc. has a contract with American International Car Rentals to provide automobiles at SFO and SJC. Participants must contact Bionetics staff at least 24 hours before arrival to confirm arrival airport and time.

ACCOMODATIONS

Flight crews will be accomodated at the **County Inn** in Mountain View, CA. The hotel is located at the junction of the Bayshore Freeway (US Route 101) and Moffett Boulevard. Moffett Boulevard is approximately 25 miles southeast of SFO on Route 101, which borders SFO, and approximately 10 miles west of SJC on the same route, which runs just north of the airport. The rooms will be paid for by Bionetics, Inc.

MEALS

There is a Denny's Restaurant, open 24 hours, adjacent to the County Inn; a list and map of other restaurants in the area will be furnished during training. Lunch will be furnished in the MVSRF Pilots' Lounge on the day of the experiment. A check for per diem expenses will be provided during training.

TRAINING

Flight crews will report to the NASA Visitors' Center, 500 feet to the left of the main gate of Moffett Naval Air Station, by 2:00 PM on the day preceding their experiment. The Moffett Naval Air Station is just north of Route 101 on Moffett Blvd. At the Visitors' Center, they will receive personal and auto passes good for entry throughout their stay. They will then drive to Building N-257 in the NASA-Ames complex, where they will be met by the project staff. An approximate training schedule is attached.

TELEPHONE NUMBERS

Project staff:	OFFICE	HOME
Sheryl S. Chappell, Principal Investigator	415-694-6909	415-854-7192
Barry Scott, Coprincipal Investigator	415-694-6379	408-252-4284
David Gates, MVSRF Experiment Manager	415-694-6737	
Bionetics, Inc., staff		
Gail Bennett-Hiley	415-694-5118	415-964-2518
Ranita Dalton	415-694-5118	408-298-8793

If crews are delayed in transit, they are asked to telephone any of the above persons for instructions.

EXPERIMENT SCHEDULE

First day:

1400	Arrive at NASA Visitor Center; pick up badges
1410	Arrive at Facility; met by MVSRF staff
1420	Fill out Bionetics and NASA forms
1430	Begin Facility Safety Briefing
1450	Break
1500	Boeing 727-232 orientation and simulator flight
1600	Begin TCAS training
1730	Questions and answers; discussion
1800	(approximate) Released for evening

Second day

0730	Arrive at Facility; met by staff; coffee
0745	Dispatch procedures
0830	Begin flying schedule
1300	(approximate) Lunch in Facility
1330	(approximate) Resume flying schedule
1745	Complete flying schedule; debriefing; fill out questionnaires
1900	(approximate) Released for evening

Third day

The third day will be utilized only if equipment malfunctions make it necessary to abort the experiment on the previous day. Crew availability for a third day will determine whether or not the option can be utilized.

First day will be a Monday or Wednesday as assigned by participating air carriers.

Appendix A2: FLIGHT PLAN AND AIRCRAFT LOAD DATA

Note: Appendix A2 was sent to the air carriers, who constructed flight plans and dispatched papers in their own formats. These data and the weather data shown in Appendix J were used by air carriers to prepare flight plans, load sheets and weather sheets in their own formats. The formatted data were returned to NASA and were supplied to the experimental crews prior to flight.

TCAS EXPERIMENT SCENARIOS: FLIGHT ROUTES

Note: These flight routes are the Center-stored flight plans for the routes to be flown in the TCAS study.

FLT.NO.	FROM: APT	SID	TRANS	FLIGHT ROUTE		ARVL	TO: APT	ALT/FL
712:	SFO	SHOR5	ECA				SCK	11000
	SCK	STKN5	BUSHY	J1 AVE	FIM	FIM2	LAX	FL 330
713:	LAX	GMN6	EHF	J65	RPI	WRAPS3	SMF	FL 310
	SMF		SAC			RISTI1	SFO	11000
716:	SFO	CUIT8	SAC				SMF	10000
	SMF	FROG04	FRA	J7	DERBB	FIM2	LAX	FL 330
715:	LAX	GMN6	EHF	J65	RPI	MOD	SCK	FL 310
	SCK	STKN5				CEDES	SFO	11000

```
712:SFO-SCK  SFO::OAK ECA 11000 ALT:SMF
 TO:    DIST     TIME     ALT       BURN
----------------------------------------
 OAK  10/ 10
 TOC              6/  6  11000    2.1/ 2.1
 TOD              2/  8           0.3/ 2.4
 ECA  50/ 60
 APT  15/ 75  12/ 20              1.1/ 3.5
----------------------------------------
0:20/0:32 GS 225   0.8T 3.5B 1.0H 2.6A 7.0R 7.4F 22.3T

EMPTY WT          101700
CARGO       3100
CREW  8
FPAX  2
YPAX 50
     60   10200  13300
FUEL             22300
                ------
RGW              137300
EST LGW          133000
```

```
712:SCK-LAX  SCK STKN5:BUSHY J1 AVE:FIM1 LAX FL330 NO ALT REQ
 TO:     DIST     TIME     ALT       BURN
----------------------------------------
BUSHY  42/ 42
 TOC             22/ 22  FL330    6.3/ 6.3
 AVE  132/174
 TOD             11/ 33           1.7/ 8.0
 FIM   94/268
 SMO   35/303
 APT   20/323  25/ 58             1.8/ 9.8
----------------------------------------
0:58/1:08 GS 334   0.8T 9.8B 7.0R 17.6T

EMPTY WT          101700
CARGO      14750
CREW  8
FPAX  3
YPAX 92
    103   17510  32260
FUEL             18000
                ------
RGW              151960
EST LGW          141760
```

```
713:LAX-SMF  LAX GMN6:EHF J65 RPI WRAPS3 SMF FL310 NO ALT REQ
 TO:    DIST     TIME    ALT       BURN
---------------------------------------
 GMN   60/ 60
 EHF   42/102
 TOC            27/ 27  FL350   7.7/ 7.7
 RPI   91/193
 TOD             8/ 35          1.3/ 9.0
 SAC  126/319
 SMF   28/347   24/ 59          1.3/10.3
---------------------------------------
0:59/1:10 GS 353   0.8T 10.3B 7.0R 5.9F 24.0T

EMPTY WT           101700
CARGO       16150
CREW  8
FPAX  6
YPAX121
    135     22950   39100
FUEL                24000
                   ------
RGW                164800
EST LGW            154000
```

```
713:SMF-SFO  SMF SAC:RISTI1 SFO 11000 NO ALT REQ
 TO:    DIST     TIME    ALT       BURN
---------------------------------------
 SAC   15/ 15
 TOC             5/  5  11000   2.0/ 2.0
CEDES  55/ 70
 TOD            10/ 15          1.7/ 3.7
 SFO   36/106   12/ 27          1.0/ 4.7
---------------------------------------
0:27/0:37 GS 236   0.8T 4.7B 7.0R 12.5T

EMPTY WT           101700
CARGO        6700
CREW  8
FPAX 13
YPAX129
    150     25500   32200
FUEL                13000
                   ------
RGW                146900
EST LGW            141900
```

```
716:SFO-SMF  SFO CUIT8:SAC SMF 11000 NO ALT REQ
 TO:     DIST    TIME    ALT       BURN
---------------------------------------
REBAS  20/ 20
 TOC             4/  4  11000    2.0/ 2.0
 TOD             7/ 11           1.0/ 3.0
 SAC   50/ 70
 SMF   28/ 98  13/ 24            1.2/ 4.2
---------------------------------------
0:27/0:37 GS 245  0.8T 4.2B 7.0R 10.5F 22.5T

EMPTY WT          101700
CARGO       6250
CREW  8
FPAX  2
YPAX 77
     87    14790  21040
FUEL              22500
                 ------
RGW               145240
EST LGW           140540
```

```
716:SMF-LAX  SMF FROG04:FRA J7 DERBB:FIM2 LAX FL330 NO ALT REQ
 TO:     DIST    TIME    ALT       BURN
---------------------------------------
FROGO  65/ 65
 TOC            15/ 15  FL330    4.8/ 4.8
 FRA   73/138
DERBB 111/249
 TOD            24/ 39           3.2/ 8.0
 FIM   65/314
 LAX   65/379   24/ 63           1.7/ 9.7
---------------------------------------
1:03/1:13 GS 361   0.8T 9.7B 7.0R 17.5T

EMPTY WT          101700
CARGO      14250
CREW  8
FPAX  9
YPAX 72
     89    15130  29380
FUEL              17500
                 ------
RGW               148580
EST LGW           138580
```

```
715:LAX-SCK  LAX GMN6:EHF J65 RPI MOD SCK FL310 ALT:SMF
 TO:     DIST    TIME    ALT      BURN
----------------------------------------
 GMN    60/ 60
 TOC            16/ 16  FL310   4.5/ 4.5
 EHF    42/102
 RPI    91/193
 TOD            13/ 29          1.9/ 6.4
 ECA    94/287
 APT     4/291  21/ 50          1.4/ 7.8
----------------------------------------
0:50/1:02 GS 349  0.8T 7.8B 7.0R 1.0H 3.0A 19.5T

EMPTY WT          101700
CARGO       2675
CREW  8
FPAX  3
YPAX 21
     32     5440    8115
FUEL               19500
                  ------
RGW               129315
EST LGW           121000
```

```
715:SCK-SFO  SCK STKN5:CEDES SFO 10000 NO ALT REQ
 TO:     DIST    TIME    ALT      BURN
----------------------------------------
 TOC             5/  5  10000   1.7/ 1.7
CEDES   40/ 40
 TOD             4/  9          0.8/ 2.5
 SFO    36/ 76  11/ 20          0.8/ 3.3
----------------------------------------
0:20/0:30 GS 228   0.8T 3.3B 7.0R 11.1T

EMPTY WT          101700
CARGO       3190
CREW  8
FPAX 13
YPAX 18
     27     4590    7780
FUEL               11100
                  ------
RGW               120580
EST LGW           116900
```

Appendix B: SUBJECT FLIGHT TIME QUESTIONNAIRE

NASA/FAA TCAS INFORMATION TRANSFER EXPERIMENT

DATA FORM: To be filled out by each crew member on arrival

EXPERIMENT NUMBER (investigator will provide this) ____________

Your age ____ FAA Medical Certificate Class ____ Visual restrictions? ____

Cockpit position: Captain ______ First Officer ______ Second Officer _____

Currently flying (aircraft, position) ____________________________________

Total flying time __________ Boeing 727 flying time __________

Time in cockpit position __________ Time last 90 days __________

Most recent P/C or P/T (month, year) __________

Please characterize your operational flying during the last 90 days:

Predominantly: Night ______ Short-haul ______ Average flight segments/day:

Day ______ Long-haul ______ ________

Do you consider yourself a "morning person" or an "evening person"? _______

Appendix C: TCAS EXPERIMENTAL DESIGN

The TCAS experiment utilized a counterbalanced pseudo-random complete blocks design. There were four experimental conditions in which the amount of information made available to subjects regarding potentially conflicting air traffic was varied. Condition 1 was a control condition. Conditions 2, 3 and 4 provided TCAS systems. In condition 2, a minimal TCAS system without a traffic display was used. In condition 3, a planform display of other traffic was provided on the weather radar scope only when a conflict had been detected. In condition 4, a full-time display of all surrounding traffic was provided.

Sixteen three-person flight crews were provided by 11 U. S. air carriers. Four flight crews were studied under each of the four experimental conditions. Each crew was studied only once, under one of the four conditions.

Each crew flew the same eight flight scenarios in one of two orders (Vol. I, table 3). Half of the flights were conducted under twilight conditions, half under night conditions; this variable was counterbalanced across crews and experimental conditions. Twilight/night ambient illumination was varied to simulate the presence or absence of a visible horizon. It is easier to evaluate the relative vertical motion of a target aircraft if a horizon is present.

Half the crews flew each block of four flights during the morning, the other half during the afternoon, in an attempt to counterbalance for the possible effects of fatigue. Fatigue effects, however, and possible learning effects as the crews became more familiar with TCAS, were confounded in this design.

First officers and Captains flew alternate legs; equal numbers of Captains and First Officers acted as flying pilot for each flight scenario, to evaluate the probability of detecting targets when each was flying or non-flying pilot.

Eight flight scenarios were constructed for this experiment. The weather, ATC instructions and all events presented to subjects were scenario-dependent (i.e. a particular target, ATC situation or malfunction was always presented in conjunction with the same specific flight leg).

Each scenario was implemented in three documents: software instructions in the SEL computer which drove the 727 simulator and the Image II visual system, software instructions in the VAX11/750 simulator which drove the ATC simulator and TCAS logic, and a written script used by the air traffic controllers and keyboard aircraft pilots (Appendix K).

EXPERIMENT MATRIX

	First leg	TCAS 1	TCAS 2	TCAS 3	TCAS 4
Flight crew 1	Captain	1111	2111	3111	4111
Flight crew 2	F/O	1221	2221	3221	4221
Flight crew 3	Captain	1312	2312	3312	4312
Flight crew 4	F/O	1422	2422	3422	4422

Four-digit identifiers identify each unique experiment:

Where i = TCAS Condition (1-4)
j = Crew number (1-4)
k = Flight sequence (1 = SFO-SFO, 2 = LAX-LAX)
l = light conditions (1 = twilight/night, 2 = reverse)

Appendix D1: TCAS TRAINING NARRATIVE FOR CONDITION 2

TCAS II WITHOUT TRAFFIC DISPLAY

After many years of engineering and development, the FAA, avionics manufacturers, and airlines are ready to operationally test the Traffic-Alert and Collision Avoidance System or TCAS. As part of this evaluation, NASA and the FAA have joined in this study of the pilots' use of information concerning traffic conflicts and evasive maneuvers.

The TCAS is a backup to the current air traffic control system and the see-and-avoid practice. It is an independent, airborne system that is only activated when these methods of separation have failed.

The TCAS system continually interrogates the transponders of nearby aircraft. The TCAS computer uses this information to predict their flight paths. If an aircraft is deemed a potential threat by TCAS, you will be advised of its presence approximately 40 seconds before the system projects a conflict. At 20 to 25 seconds before closest approach, you will be told how to take evasive action, if necessary. If the other aircraft also has TCAS, the maneuvers will be coordinated.

Because of current system limitations, only vertical maneuvers are used and these maneuvers can only provide separation from altitude reporting (mode C) aircraft. TCAS will only provide a traffic advisory for aircraft equipped with non altitude reporting transponders (mode A). *TCAS does not work at all for airplanes without transponders.*

In summary, TCAS tells you two things: first, it cautions you that you may be getting too close to an aircraft and second, it advises you what to do, if anything, to resolve a traffic conflict.

Now let's examine the TCAS displays and their associated alerts and warnings, and do so in the order that they will appear to you in the cockpit.

When TCAS determines that within the next 40 seconds an aircraft could come too close to you, you will hear a tone and at the same time see an amber caution light under the glareshield.

These precursors can be cancelled by you and are designed to draw your attention out of the cockpit to search for traffic This is the most common form of TCAS alert, the traffic advisory.

As TCAS continues to monitor the traffic it may become either less threatening, or more threatening.

In seven out of eight cases the traffic will become less threatening. When this happens the caution light & tone will stop (if you haven't already cancelled them).

If the "intruder" continues to be a threat, you will get another light and aural warning at 20-25 seconds from the time of closest approach. This will occur very rarely. More about these alerts later.

Now let's review the series of events which occurs as TCAS first elects to announce threatening traffic.

* First the tone and the light.

* Our attention is drawn out of the cockpit, scanning for the threat traffic.

The traffic advisory is meant to be an aid, not a replacement for the "see and avoid" practice. Remember, only aircraft with transponders will be detected by TCAS.

Should you receive a traffic advisory and this collision threat continue to develop, the IVSI will provide you with a recommended course of action which you may use to resolve the impending conflict.

These IVSI's appear, on initial examination, to be very similar to the conventional ones which they replace. However, they have a series of lighted amber segments around the outer edge of the instrument which correspond to the vertical rates depicted on the basic IVSI. Since TCAS, in it's present form, will provide conflict resolution only in the vertical plane, these lights serve as an ideal means of depicting what that vertical maneuver should be. The operational procedure to be used when performing evasive maneuvers annunciated on the IVSI is simply, "Keep the needle out of the lights".

When a TCAS traffic advisory persists in being a threat, two situations can occur: traffic will pass safely if you continue as you are, or you will have to take evasive action. In the first case your vertical speed is OK, the needle is out of the lights.

In the second, you have to climb or descend to get the needle out of the lights.

Half the time TCAS will issue the advisory which requires no action from the pilot, other than recognition of what the system is telling you *not* to do. You may be flying level, and that will keep you clear of the traffic, but if you were thinking of starting a descent, don't do so now. Because this type of advisory requires no change in aircraft flight path, it is presented with less urgency. This preventative advisory is a caution. A tone will sound with an amber caution light. Look at the IVSI lights for the area you are *not* to fly into. The basic ground rule for the use of TCAS still applies; keep the IVSI needle out of the lights.

When action is required, a warning siren and light get your attention and a voice states the same message depicted on the IVSI.

You will hear the following commands annunciated over a speaker in the cockpit and you will see these lights on your IVSI. You should respond *promptly,* by smoothly maneuvering your aircraft in order to get your vertical rate needle "out of the lights".

* **siren, "climb, climb"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of climb. TCAS evasive maneuvers are predicated on a 2000 foot per minute rate. It is not necessary to exceed this. In fact if you climb at a rate greater than 2000 feet per minute, this could cause you to go into another aircraft's airspace.

* **siren, "descend, descend"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of descent, no less or no more.

* **siren, "adjust vertical speed"** Again, keep the vertical rate needle out of the lights. A special case of this command is in an encounter with two aircraft where one is above and one is below. The only safe, unlighted part is ± 250 feet per minute, showing you to fly level.

* **siren, "descend to cross"** You will hear this advisory when you have to cross through the

intruder's altitude for avoidance. If the intruder is climbing at a high rate but still below you, as you can see in this diagram, your best avoidance strategy is to maneuver towards the intruder's present position. In these situations where you must cross through the traffic's altitude, you will hear **"descend to cross"** or **"climb to cross"**.

* In extremely rare situations, when the TCAS logic cannot resolve the conflict, you will hear **"unable to command"**, and at the same time all the lights on the IVSI will flash on and off. When you get this message, you must resolve the conflict yourself using all available information. This could occur, for example, if the intruder aircraft were to maneuver making a previously issued solution inappropriate, (as in this diagram) or if you have maneuvered differently than TCAS prescribed.

* You will be surprised how little displacement is required to provide separation, 300 feet is the average. The command for evasive action will disappear very quickly. The lights on the IVSI will go out and you will hear the message **"clear of conflict"**. Promptly and smoothly return to your assigned altitude or flight profile. Safe use of TCAS depends on you minimizing how far you have deviated from your clearance.

Since the evasive action required by TCAS to resolve most conflicts is small in distance and duration, most of these maneuvers will be of little consequence to ATC. However, you may wish to notify ATC that a situation occurred requiring you to maneuver based on a TCAS advisory, when time and cockpit work load permit.

One other note regarding the use of the IVSI: if you are descending or climbing at a rate that is greater than 2000 feet per minute and TCAS decides you should continue doing what you are doing, the arcs in the IVSI will only light up to reflect a maximum rate of 2000 feet per minute. Maintain your *present rate,* until you no longer have the climb or descend lights. This trait of the current system is due to a limitation within the IVSI display and eventually will be corrected.

Now that you have had a chance to review the correct responses to TCAS, let's watch a typical encounter and review the appropriate crew procedures used in dealing with it.

TCAS detects a potential threat and cautions the crew.

The Pilot Flying, in this case the captain, immediately begins a visual search for the intruder. The Pilot Flying also may cancel the light on the glareshield.

The Pilot Not Flying states "Traffic" as an acknowledgment and will then join the pilot flying in the visual search for the intruder.

Should the intruder continue to pose a threat and evasive action become necessary, BOTH pilots will clear the airspace into which the maneuver will take them while the Pilot Flying promptly, and smoothly, complies with the TCAS by getting the needle out of the lights.

When the words "Clear of conflict" are heard the Pilot Not Flying will state "Clear" and the Pilot Flying will, as smoothly and expeditiously as practical, return the aircraft to its previously assigned flight path.

The second officer will assist in looking for traffic, monitor the situation and advise of any discrepancies.

Let's review then the basic ground rules regarding the use of TCAS and its displays.

1. The traffic advisory is intended to be used as an aid to visual acquisition, and to prepare the crew mentally and physically for possible evasive action. If you have established visual contact with the threat traffic, you may maneuver your aircraft without being told to do so by TCAS. However, this greatly reduces the accuracy of TCAS to predict the separation. The maneuver logic provides ample time to obtain separation once conditions require it.

2. Prior to taking the evasive action displayed on the IVSI, CLEAR THE AIRSPACE INTO WHICH YOU ARE GOING TO MANEUVER.

3. TCAS evasive maneuvers shall be complied with in a TIMELY AND GENTLE FASHION.

4. Proper response to resolutions displayed on the IVSI will be to KEEP THE RATE NEEDLE OUT OF THE LIGHTS.

5. If your vertical speed needle is already out of the lights, MAINTAIN YOUR CURRENT RATE, rather than reduce to 2000 feet per minute.

6. Remember to always MINIMIZE YOUR DEVIATION FROM ATC CLEARANCE

7. Once the threat has been resolved and you hear **"Clear of conflict"** PROMPTLY AND SMOOTHLY RETURN TO YOUR PREVIOUSLY ASSIGNED FLIGHT PATH.

8. COMPLIANCE WITH A TCAS MANEUVER IS EXPECTED, UNLESS, IN THE JUDGEMENT OF THE PILOT-IN-COMMAND, DOING SO WOULD PRESENT A GREATER HAZARD TO THE SAFETY OF THE FLIGHT.

9. And finally, although TCAS is an extremely useful tool for insuring aircraft separation, it will only detect aircraft with operating transponders, and will only resolve conflicts with those that also have accurate altitude information. It is therefore still somewhat limited in its' capabilities and SHOULD NOT BE USED AS A SUBSTITUTE FOR NORMAL CREW VIGILANCE OUTSIDE THE COCKPIT.

TCAS represents the results of years of research and development by government and industry. It has been developed for your use. Now your help is needed to evaluate the system in an operational environment. Even though this evaluation is in a simulator, please conduct this flight as you normally would. With your help in the implementation of TCAS, the high level of safety which currently exists in our Air Transport System will be even further enhanced.

Appendix D2: TCAS TRAINING NARRATIVE FOR CONDITION 3

TCAS II WITH TRAFFIC DISPLAY ONLY DURING CONFLICTS

After many years of engineering and development, the FAA, avionics manufacturers, and airlines are ready to operationally test the Traffic-Alert and Collision Avoidance System or TCAS. As part of this evaluation, NASA and the FAA have joined in this study of the pilots' use of information concerning traffic conflicts and evasive maneuvers.

The TCAS is a backup to the current air traffic control system and the see-and-avoid practice. It is an independent, airborne system that is only activated when these methods of separation have failed.

The TCAS system continually interrogates the transponders of nearby aircraft. The TCAS computer uses this information to predict their flight paths. If an aircraft is deemed a potential threat by TCAS, you will be advised of its presence approximately 40 seconds before the system projects a conflict. At 20 to 25 seconds before closest approach, you will be told how to take evasive action, if necessary. If the other aircraft also has TCAS, the maneuvers will be coordinated.

Because of current system limitations, only vertical maneuvers are used and these maneuvers can only provide separation from altitude reporting (mode C) aircraft. TCAS will only provide a traffic advisory for aircraft equipped with non altitude reporting transponders (mode A). *TCAS does not work at all for airplanes without transponders.*

In summary, TCAS tells you two things: first, it cautions you that you may be getting too close to an aircraft and second, it advises you what to do, if anything, to resolve a traffic conflict.

Now let's examine the TCAS displays and their associated alerts and warnings, and do so in the order that they will appear to you in the cockpit.

When TCAS determines that within the next 40 seconds an aircraft could come too close to you, you will hear a tone and at the same time see an amber caution light under the glareshield.

These precursors can be cancelled by you and are designed to draw your attention to the traffic advisory display which constitutes one of two primary TCAS displays. The CRT which currently provides weather radar information now takes on this additional function and will now show the most common form of TCAS alert, the traffic advisory. It will come to life when TCAS predicts an aircraft could come too close to you. The information displayed on the CRT is designed to help establish visual contact with the threat traffic and includes:

* A chevron in the lower center of the CRT represents your aircraft.

* A circle with a 2 mile radius is made up of asterisks at each o'clock position.

* The range between your aircraft symbol and the edge of the display is 6 miles in front, 4 miles either side, and approximately 3 miles behind.

* And, since the CRT will only come to life when TCAS has something it wants to show you,

an amber triangle will appear at the "intruder's" relative position to you. This triangle is accompanied by additional information about this airplane.

That information is in the form of a data block consisting of three or four symbols as follows:

* A plus sign indicating that the traffic is *above* you or a minus sign indicating the traffic is *below* you.

* A two digit number indicating the number of feet, in one hundred foot increments, that the aircraft is above or below you. However, if the traffic's altitude is unknown, in other words, the intruder's Mode "C" is inoperative or, the aircraft is not equipped with it, two question marks will appear in this block instead of a number.

* If the aircraft is climbing or descending greater than 500 feet per minute, you will see an arrow indicating the direction of movement.

All of this information is meant to provide a timely and clear reference to assist you in seeing the other air traffic which may pose a threat to you. Although the bearing information provided to you is accurate to about eight degrees, it is *not* accurate enough to be used for evasive maneuvers. Therefore the first rule for operating TCAS is that you *may not* maneuver the aircraft based *solely* on the information displayed on the traffic advisory display.

As TCAS continues to monitor the traffic it may become either less threatening, or more threatening.

In seven out of eight cases the traffic will become less threatening. When this happens the indicator will go blank and the caution light & tone will stop (if you haven't already cancelled them).

* If the "intruder" continues to be a threat, it's color will change to red at 20 to 25 seconds from the time of closest approach. A red target is the highest priority, and is a call for action on the part of the pilot. They will be seen very rarely. More about "red targets" later.

Now let's review the series of events which occurs as TCAS first elects to show threatening traffic.

* First the tone and the light.

* Our attention is drawn to the CRT where we see an amber triangle and its associated data block 1 mile outside the 2 mile range ring and about our 3 o'clock position. The data block indicates that the intruder is 600 feet below us and climbing at a rate greater than 500 feet per minute.

Were ATC to provide us with the same advisory they would say, "Traffic 3 o'clock 3 miles climbing through your altitude".

Also on the CRT, are two other targets shown in blue. These targets are commonly referred to as "proximate traffic" and are displayed, along with our primary target of interest, if they are within 4 miles and + or - 1200 feet of our altitude. These aircraft are displayed to improve our situational awareness and aid in locating threat traffic out of the window.

When a traffic advisory is displayed, only the three aircraft of greatest threat to you will be shown.

From time to time you may see two other types of symbols on your traffic advisory display. They are:

* An amber square used to represent an aircraft which is outside the range scale of the CRT.

* And on the very rare occasion that TCAS is unable to track the bearing of an aircraft, due to temporary antenna shielding, you will see a data block in the upper left corner of the CRT which gives, in the appropriate color code, the range and relative altitude of the intruder.

The computer is continually sorting all aircraft which are being tracked by TCAS. Any time you wish to observe the 8 most important aircraft which TCAS is tracking, merely push the traffic toggle switch on the control panel. The traffic advisory display will display the top eight aircraft of interest for fifteen seconds, even though TCAS may be tracking more than 8.

In summary, the traffic advisory display when properly used, is meant to be an aid, not a replacement for the "see and avoid" practice. Remember, only aircraft with transponders will be shown.

Should you receive a traffic advisory and this collision threat continue to develop, the second of TCAS's' primary displays, the IVSI will provide you with a recommended course of action which you may use to resolve the impending conflict.

These IVSI's appear, on initial examination, to be very similar to the conventional ones which they replace. However, they have a series of lighted amber segments around the outer edge of the instrument which correspond to the vertical rates depicted on the basic IVSI. Since TCAS, in it's present form, will provide conflict resolution only in the vertical plane, these lights serve as an ideal means of depicting what that vertical maneuver should be. The operational procedure to be used when performing evasive maneuvers annunciated on the IVSI is simply, "Keep the needle out of the lights".

When a TCAS traffic advisory persists in being a threat, two situations can occur: traffic will pass safely if you continue as you are, or you will have to take evasive action. In the first case your vertical speed is OK, the needle is out of the lights.

In the second, you have to climb or descend to get the needle out of the lights.

Half the time TCAS will issue the advisory which requires no action from the pilot, other than recognition of what the system is telling you *not* to do. You may be flying level, and that will keep you clear of the traffic, but if you were thinking of starting a descent, don't do so now. Because this type of advisory requires no change in aircraft flight path, it is presented with less urgency. This preventative advisory is a caution. A tone will sound with an amber caution light. Look at the IVSI lights for the area you are *not* to fly into. The basic ground rule for the use of TCAS still applies; keep the IVSI needle out of the lights.

When action is required, a warning siren and light get your attention and a voice states the same message depicted on the IVSI.

You will hear the following commands annunciated over a speaker in the cockpit and you will see these lights on your IVSI. You should respond *promptly,* by smoothly maneuvering your aircraft in order to get your vertical rate needle "out of the lights".

* **siren, "climb, climb"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of climb. TCAS evasive maneuvers are predicated on a 2000 foot per minute rate. It is not necessary to exceed this. In fact if you climb at a rate greater than 2000 feet per minute, this could cause you to go into another aircraft's airspace.

* **siren, "descend, descend"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of descent, no less or no more.

* **siren, "adjust vertical speed"** Again, keep the vertical rate needle out of the lights. A special case of this command is in an encounter with two aircraft where one is above and one is below. The only safe, unlighted part is ± 250 feet per minute, showing you to fly level.

* **siren, "descend to cross"** You will hear this advisory when you have to cross through the intruder's altitude for avoidance. If the intruder is climbing at a high rate but still below you, as you can see in this diagram, your best avoidance strategy is to maneuver towards the intruder's present position. In these situations where you must cross through the traffic's altitude, you will hear **"descend to cross"** or **"climb to cross"**.

* In extremely rare situations, when the TCAS logic cannot resolve the conflict, you will hear **"unable to command"**, and at the same time all the lights on the IVSI will flash on and off. When you get this message, you must resolve the conflict yourself using all available information. This could occur, for example, if the intruder aircraft were to maneuver making a previously issued solution inappropriate, (as in this diagram) or if you have maneuvered differently than TCAS prescribed.

* You will be surprised how little displacement is required to provide separation, 300 feet is the average. The command for evasive action will disappear very quickly. The lights on the IVSI will go out and you will hear the message **"clear of conflict"**. Promptly and smoothly return to your assigned altitude or flight profile. Safe use of TCAS depends on you minimizing how far you have deviated from your clearance.

Since the evasive action required by TCAS to resolve most conflicts is small in distance and duration, most of these maneuvers will be of little consequence to ATC. However, you may wish to notify ATC that a situation occurred requiring you to maneuver based on a TCAS advisory, when time and cockpit work load permit.

One other note regarding the use of the IVSI: if you are descending or climbing at a rate that is greater than 2000 feet per minute and TCAS decides you should continue doing what you are doing, the arcs in the IVSI will only light up to reflect a maximum rate of 2000 feet per minute. Maintain your ***present rate,*** until you no longer have the climb or descend lights. This trait of the current system is due to a limitation within the IVSI display and eventually will be corrected.

Now that you have had a chance to review the correct responses to TCAS, let's watch a typical encounter and review the appropriate crew procedures used in dealing with it.

TCAS detects a potential threat and displays it to the crew.

The Pilot Flying, in this case the captain, looks at the traffic advisory display, approximates the position of the threat aircraft, and immediately begins a visual search for the intruder. The Pilot Flying also may cancel the light on the glareshield.

The Pilot Not Flying states "Traffic" as an acknowledgment and will also look at the traffic advisory display and will verbally interpret the display for the pilot flying by giving the range, bearing, and relative altitude of the intruder.

The Pilot Not Flying will then join the pilot flying in the visual search for the intruder.

If the Pilot Flying requires an update on the position of the intruder it will be provided by the Pilot Not Flying in order that the he can continue the visual search.

Should the intruder continue to pose a threat and evasive action become necessary, BOTH pilots will clear the airspace into which the maneuver will take them while the Pilot Flying promptly, and smoothly, complies with the TCAS by getting the needle out of the lights.

When the words "Clear of conflict" are heard the Pilot Not Flying will state "Clear" and the Pilot Flying will as smoothly and expeditiously as practical, return the aircraft to its previously assigned flight path.

The second officer will assist in looking for traffic, monitor the situation and advise of any discrepancies.

Let's review then the basic ground rules regarding the use of TCAS and its' displays.

1. The traffic advisory display is intended to be used as an aid to visual acquisition, and to prepare the crew mentally and physically for possible evasive action. MANEUVERS BASED SOLELY ON THE INFORMATION PROVIDED ON THE TRAFFIC ADVISORY DISPLAY ARE PROHIBITED. If you have established visual contact with the threat traffic, you may maneuver your aircraft without being told to do so by TCAS. However, this greatly reduces the accuracy of TCAS to predict the separation. The maneuver logic provides ample time to obtain separation once conditions require it.

2. Prior to taking the evasive action displayed on the IVSI, CLEAR THE AIRSPACE INTO WHICH YOU ARE GOING TO MANEUVER.

3. TCAS evasive maneuvers shall be complied with in a TIMELY AND GENTLE FASHION.

4. Proper response to resolutions displayed on the IVSI will be to KEEP THE RATE NEEDLE OUT OF THE LIGHTS.

5. If your vertical speed needle is already out of the lights, MAINTAIN YOUR CURRENT RATE, rather than reduce to 2000 feet per minute.

6. Remember to always MINIMIZE YOUR DEVIATION FROM ATC CLEARANCE

7. Once the threat has been resolved and you hear "Clear of conflict" PROMPTLY AND SMOOTHLY RETURN TO YOUR PREVIOUSLY ASSIGNED FLIGHT PATH.

8. COMPLIANCE WITH A TCAS MANEUVER IS EXPECTED, UNLESS, IN THE JUDGEMENT OF THE PILOT-IN-COMMAND, DOING SO WOULD PRESENT A GREATER HAZARD TO THE SAFETY OF THE FLIGHT.

9. And finally, although TCAS is an extremely useful tool for insuring aircraft separation, it will only detect aircraft with operating transponders, and will only resolve conflicts with those that also have accurate altitude information. It is therefore still somewhat limited in its' capabilities and SHOULD NOT BE USED AS A SUBSTITUTE FOR NORMAL CREW VIGILANCE OUTSIDE THE COCKPIT.

TCAS represents the results of years of research and development by government and industry. It has been developed for your use. Now your help is needed to evaluate the system in an operational environment. Even though this evaluation is in a simulator, please conduct this flight as you normally would. With your help in the implementation of TCAS, the high level of safety which currently exists in our Air Transport System will be even further enhanced.

Appendix D3: TCAS TRAINING NARRATIVE FOR CONDITION 4

TCAS II WITH CONTINUOUS DISPLAY OF TRAFFIC

After many years of engineering and development, the FAA, avionics manufacturers, and airlines are ready to operationally test the Traffic-Alert and Collision Avoidance System or TCAS. As part of this evaluation, NASA and the FAA have joined in this study of the pilots' use of information concerning traffic conflicts and evasive maneuvers.

The TCAS is a backup to the current air traffic control system and the see-and-avoid practice. It is an independent, airborne system that is only activated when these methods of separation have failed.

The TCAS system continually interrogates the transponders of nearby aircraft. The TCAS computer uses this information to predict their flight paths. If an aircraft is deemed a potential threat by TCAS, you will be advised of its presence approximately 40 seconds before the system projects a conflict. At 20 to 25 seconds before closest approach, you will be told how to take evasive action, if necessary. If the other aircraft also has TCAS, the maneuvers will be coordinated.

Because of current system limitations, only vertical maneuvers are used and these maneuvers can only provide separation from altitude reporting (mode C) aircraft. TCAS will only provide a traffic advisory for aircraft equipped with non altitude reporting transponders (mode A). *TCAS does not work at all for airplanes without transponders.*

In summary, TCAS tells you two things: first, it cautions you that you may be getting too close to an aircraft and second, it advises you what to do, if anything, to resolve a traffic conflict.

Now let's examine the TCAS displays and their associated alerts and warnings, and do so in the order that they will appear to you in the cockpit.

When TCAS determines that within the next 40 seconds an aircraft could come too close to you, you will hear a tone and at the same time see an amber caution light under the glareshield.

These precursors can be cancelled by you and are designed to draw your attention to the traffic advisory display which constitutes one of two primary TCAS displays. The CRT to the left of your weather radar will show the most common form of TCAS alert, the traffic advisory. The information displayed on the CRT is designed to help establish visual contact with the threat traffic and includes:

* An aircraft symbol in the lower center of the CRT represents your aircraft.

* A circle with a 3 mile radius is made up of tick marks at each o'clock position.

* A 5 mile range ring consists of a series of dots. (These range rings correspond to the nominal IFR separations in terminal and enroute airspace, respectively.)

* The distance between your aircraft symbol and the compass arc is selected by the range knob and is shown in the upper right corner. The heading on the compass comes from the

Captain's HSI.

* When an aircraft is predicted to come too close to you, a solid amber circle will appear at the "intruder's" relative position to you. This amber circle is accompanied by additional information about this airplane.

That information is in the form of a data block consisting of three or four symbols as follows:

* A plus sign indicating that the traffic is *above* you or a minus sign indicating the traffic is *below* you.

* A two digit number indicating the number of feet, in one hundred foot increments, that the aircraft is above or below you. However, if the traffic's altitude is unknown, in other words, the intruder's Mode "C" is inoperative or, the aircraft is not equipped with it, no altitude data block will appear.

* If the aircraft is climbing or descending greater than 500 feet per minute, you will see an arrow indicating the direction of movement.

All of this information is meant to provide a timely and clear reference to assist you in seeing the other air traffic which may pose a threat to you. Although the bearing information provided to you is accurate to about 3 degrees, it is *not* accurate enough to be used for evasive maneuvers. Therefore the first rule for operating TCAS is that you *may not* maneuver your aircraft based *solely* on the information displayed on the traffic advisory display.

As TCAS continues to monitor the traffic it may become either less threatening, or more threatening.

In seven out of eight cases the traffic will become less threatening. When this happens the caution light & tone will stop (if you haven't already cancelled them) and the solid amber circle, at the aircraft's relative location, will become a white diamond.

* If the "intruder" continues to be a threat, its symbol will change to a red square at 20-25 seconds from the time of closest approach. A red target is the highest priority, and is a call for action on the part of the pilot. They will be seen very rarely. More about "red targets" later.

Now let's review the series of events which occurs as TCAS first elects to show us threatening traffic.

* First the tone and the light.

* Our attention is drawn to the CRT where we see a solid amber circle and its associated data block at the 3 mile range ring and about our 3 o'clock position. The data block indicates that the intruder is 600 feet below us and climbing at a rate greater than 500 feet per minute.

Were ATC to provide us with the same advisory they would say, "Traffic 3 o'clock 3 miles climbing through your altitude".

Also on the CRT, are two other white diamond aircraft symbols. These targets are commonly referred to as "proximate traffic" and are displayed, along with our primary target of interest. If they are within 4 miles and + or - 1200 feet of our altitude they will be filled diamonds. If they are at a greater distance, the diamonds will not be filled. These aircraft are displayed to improve our situational awareness and aid in locating threat traffic out of the window.

From time to time you may see two other types of symbols on your traffic advisory display. They are:

* An amber arrow pointing to an aircraft which is outside the range scale of the CRT. Selecting a higher range setting will bring the target onto the display.

* And on the very rare occasion that TCAS is unable to track the bearing of a threat aircraft, due to temporary antenna shielding, you will see a message at the top, in the appropriate color for the level of threat.

The computer is continually evaluating the flight paths of all the aircraft which are being tracked by TCAS. The traffic advisory display will display any of these that are in the range and altitude band you have selected.

The traffic advisory display control panel, located directly below the display, is used to select the horizontal and vertical ranges at which you wish to see traffic.

The range knob provides a choice of four full scale ranges on the display - three, five, ten and twenty miles. The altitude select switch is used to select the altitude band of interest for display. In the normal position, all aircraft within $\pm$2700 feet of your own altitude will be displayed. In the "above" position, all aircraft being tracked above will be displayed in addition to the "normal" altitude slice, that is - twenty-seven hundred feet below, to about 7000 feet above - the limit of vertical surveillance. Likewise, in the "below" position, aircraft will be displayed within + 2700 feet to -7000 feet from your altitude.

Range scales and altitude slices may be selected at pilot option. As a start, it is suggested that 10 miles be used at takeoff, 20 miles in cruise, and selectively smaller scales during descent to landing. The selections made on the display control panel have no effect on the ability to respond correctly to a TCAS maneuver, so experiment to see what seems most useful.

The relative altitude/flight level switch provides a means of displaying the actual flight level of the target aircraft, rather than the normal altitude relative to your aircraft in hundreds of feet. This switch is spring loaded to the relative altitude position and the display of flight levels will revert to relative altitudes 15 seconds after depressing the switch.

In summary, the traffic advisory display when properly used, is meant to be an aid, not a replacement for the "see and avoid" practice. Remember, only aircraft with transponders will be shown.

Should you receive a traffic advisory and this collision threat continue to develop, the second of TCAS's' primary displays, the IVSI will provide you with a recommended course of action which you may use to resolve the impending conflict.

These IVSI's appear, on initial examination, to be very similar to the conventional ones which they replace. However, they have a series of lighted amber segments around the outer edge of the instrument which correspond to the vertical rates depicted on the basic IVSI. Since TCAS, in it's present form, will provide conflict resolution only in the vertical plane, these lights serve as an ideal means of depicting what that vertical maneuver should be. The operational procedure to be used when performing evasive maneuvers annunciated on the IVSI is simply, "Keep the needle out of the lights".

When a TCAS traffic advisory persists in being a threat, two situations can occur: traffic will pass safely if you continue as you are, or you will have to take evasive action. In the first case your vertical speed is OK, the needle is out of the lights.

In the second, you have to climb or descend to get the needle out of the lights.

Half the time TCAS will issue the advisory which requires no action from the pilot, other than recognition of what the system is telling you *not* to do. You may be flying level, and that will keep you clear of the traffic, but if you were thinking of starting a descent, don't do so now. Because this type of advisory requires no change in aircraft flight path, it is presented with less urgency. This preventative advisory is a caution. A tone will sound with an amber caution light. Look at the IVSI lights for the area you are *not* to fly into. The basic ground rule for the use of TCAS still applies; keep the IVSI needle out of the lights.

When action is required, a warning siren and light get your attention and a voice states the same message depicted on the IVSI.

You will hear the following commands annunciated over a speaker in the cockpit and you will see these lights on your IVSI. You should respond *promptly*, by smoothly maneuvering your aircraft in order to get your vertical rate needle "out of the lights".

* **siren, "climb, climb"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of climb. TCAS evasive maneuvers are predicated on a 2000 foot per minute rate. It is not necessary to exceed this. In fact if you climb at a rate greater than 2000 feet per minute, this could cause you to go into another aircraft's airspace.

* **siren, "descend, descend"** Begin a quarter G maneuver in order to establish a 2000 foot per minute rate of descent, no less or no more.

* **siren, "adjust vertical speed"** Again, keep the vertical rate needle out of the lights. A special case of this command is in an encounter with two aircraft where one is above and one is below. The only safe, unlighted part is ± 250 feet per minute, showing you to fly level.

* **siren, "descend to cross"** You will hear this advisory when you have to cross through the intruder's altitude for avoidance. If the intruder is climbing at a high rate but still below you, as you can see in this diagram, your best avoidance strategy is to maneuver towards the intruder's present position. In these situations where you must cross through the traffic's altitude, you will hear **"descend to cross"** or **"climb to cross"**.

* In extremely rare situations, when the TCAS logic cannot resolve the conflict, you will hear **"unable to command"**, and at the same time all the lights on the IVSI will flash on and off. When you get this message, you must resolve the conflict yourself using all available information. This could occur, for example, if the intruder aircraft were to maneuver making a previously issued solution inappropriate, (as in this diagram) or if you have maneuvered differently than TCAS prescribed.

* You will be surprised how little displacement is required to provide separation, 300 feet is the average. The command for evasive action will disappear very quickly. The lights on the IVSI will go out and you will hear the message **"clear of conflict"**. Promptly and smoothly return to your assigned altitude or flight profile. Safe use of TCAS depends on you minimizing how far you have deviated from your clearance.

Since the evasive action required by TCAS to resolve most conflicts is small in distance and duration, most of these maneuvers will be of little consequence to ATC. However, you may wish to notify ATC that a situation occurred requiring you to maneuver based on a TCAS advisory, when time and cockpit work load permit.

One other note regarding the use of the IVSI: if you are descending or climbing at a rate that is greater than 2000 feet per minute and TCAS decides you should continue doing what you are doing, the arcs in the IVSI will only light up to reflect a maximum rate of 2000 feet per minute. Maintain your *present rate,* until you no longer have the climb or descend lights. This trait of the current system is due to a limitation within the IVSI display and eventually will be corrected.

A back up source of the information on the IVSI appears in the upper left corner of the traffic display. This symbology consists of green arrows for climb and descend advisories, and the international "do not" symbol over white arrows to indicate that vertical speed must be limited either up or down. Refer to the IVSI eyebrow lights to see what the limit is.

Maneuver advisories which might be triggered when intentionally flying close to another aircraft should be inhibited. For example, when parallel visual approaches are in progress to runways spaced less than 3000 feet apart, select "TA only" on the transponder mode switch. This will prevent maneuvering advisories being issued for planned, close separations. A traffic advisory may still be issued, which will call your attention to the location of the aircraft on the other approach. The normal operating position for the transponder switch is TCAS, which provides full functioning of both the TCAS and the transponder.

Now that you have had a chance to review the correct responses to TCAS, let's watch a typical encounter and review the appropriate crew procedures used in dealing with it.

TCAS detects a potential threat and displays it to the crew.

The Pilot Flying, in this case the captain, looks at the traffic advisory display, approximates the position of the threat aircraft, and immediately begins a visual search for the intruder. The Pilot Flying also may cancel the light on the glareshield.

The Pilot Not Flying states "Traffic" as an acknowledgment and will also look at the traffic advisory display and will verbally interpret the display for the pilot flying by giving the range, bearing, and relative altitude of the intruder.

The Pilot Not Flying will then join the pilot flying in the visual search for the intruder.

If the Pilot Flying requires an update on the position of the intruder it will be provided by the Pilot Not Flying in order that the he can continue the visual search.

Should the intruder continue to pose a threat and evasive action become necessary, BOTH pilots will clear the airspace into which the maneuver will take them while the Pilot Flying promptly, and smoothly, complies with the TCAS by getting the needle out of the lights.

When the words "Clear of conflict" are heard the Pilot Not Flying will state "Clear" and the Pilot Flying will as smoothly and expeditiously as practical, return the aircraft to its previously assigned flight path.

The second officer will assist in looking for traffic, monitor the situation and advise of any discrepancies.

Let's review then the basic ground rules regarding the use of TCAS and its displays.

1. The traffic advisory display is intended to be used as an aid to visual acquisition, and to prepare the crew mentally and physically for possible evasive action. MANEUVERS BASED SOLELY ON THE INFORMATION PROVIDED ON THE TRAFFIC ADVISORY DISPLAY ARE PROHIBITED. If you have established visual contact with the threat traffic, you may maneuver your aircraft without being told to do so by TCAS. However, this greatly reduces the accuracy of TCAS to predict the separation. The maneuver logic provides ample time to obtain separation once conditions require it.

2. Prior to taking the evasive action displayed on the IVSI, CLEAR THE AIRSPACE INTO WHICH YOU ARE GOING TO MANEUVER.

3. TCAS evasive maneuvers shall be complied with in a TIMELY AND GENTLE FASHION.

4. Proper response to resolutions displayed on the IVSI will be to KEEP THE RATE NEEDLE OUT OF THE LIGHTS.

5. If your vertical speed needle is already out of the lights, MAINTAIN YOUR CURRENT RATE, rather than reduce to 2000 feet per minute.

6. Remember to always MINIMIZE YOUR DEVIATION FROM ATC CLEARANCE

7. Once the threat has been resolved and you hear **"Clear of conflict"** PROMPTLY AND SMOOTHLY RETURN TO YOUR PREVIOUSLY ASSIGNED FLIGHT PATH.

8. COMPLIANCE WITH A TCAS MANEUVER IS EXPECTED, UNLESS, IN THE JUDGEMENT OF THE PILOT-IN-COMMAND, DOING SO WOULD PRESENT A GREATER HAZARD TO THE SAFETY OF THE FLIGHT.

9. And finally, although TCAS is an extremely useful tool for insuring aircraft separation, it will only detect aircraft with operating transponders, and will only resolve conflicts with those that also have accurate altitude information. It is therefore still somewhat limited in its' capabilities and SHOULD NOT BE USED AS A SUBSTITUTE FOR NORMAL CREW VIGILANCE OUTSIDE THE COCKPIT.

TCAS represents the results of years of research and development by government and industry. It has been developed for your use. Now your help is needed to evaluate the system in an operational environment. Even though this evaluation is in a simulator, please conduct this flight as you normally would. With your help in the implementation of TCAS, the high level of safety which currently exists in our Air Transport System will be even further enhanced.

Appendix E: DESCRIPTION OF SIMULATION COMPUTER INTEGRATION

The NASA-Ames Research Center Man-Vehicle Systems Research Facility (MVSRF) was used for this study. The aircraft simulator used was a Singer-Link Boeing 727-23223 advanced technology simulator with a six degree-of-freedom motion system and a Singer Link-Miles Image II three-channel, four-window dusk-night visual system. This device is qualified under FAA part 121, Appendix H as a phase 2 simulator. The simulator is driven by a Gould SEL 3277 computer; the Image-II visual system is controlled by a dedicated special-purpose micro-processer.

The simulated aircraft operated in an air traffic control environment created by an air traffic control simulation resident in a Digital Equipment Corporation VAX11/750 computer. The simulation has three controller workstations and three keyboard pilot work stations capable of simulating up to 36 other aircraft. All workstations and the 727 simulator are interconnected by voice communications using appropriate air traffic control VHF frequencies. The gaming area simulated for this study included Oakland and Los Angeles Air Route Traffic Control Centers, and four terminal areas: Los Angeles, Sacramento, San Francisco and Stockton.

A word about the relationships among the computers and devices will explain how the simulation was constructed.

o The VAX computer accomplished the following functions:

Creation of the ATC environment, controller screens and ATC sectors, creation of navigational aids

Creation of simulated aircraft in space when triggered by information from the SEL computer regarding 727 altitude or geographic coordinates, and subsequent control of those aircraft according to prearranged instructions or on receipt of instructions from the keyboard pilots

Creation of keyboard pilot control screens

Running the winds model; transfer to the SEL of winds at 727 altitude

Provision, via VAX-SEL link, of data regarding position and altitude of visual aircraft (this information was subsequently transferred from the SEL computer to the Image microprocessor for visual presentation

Provision to the TCAS logic, also resident in the VAX, of information regarding 727 and other aircraft position and altitude

Running the TCAS logic algorithms

Generation of TCAS display and alerting commands, TCAS symbols, warning signals and aural microprocessor for presentation in the cockpit

- The SEL computer was responsible for the following:

  Running the aircraft and motion algorithms

  Creation of the Observer station screens and execution of experimenter instructions

  Transfer to the VAX and Image of 727 operating parameters

  Transmission to the TCAS alerting hardware of instructions from the VAX

  Control of weather (except winds) and turbulence

- The Image microprocessor was responsible for

  Generation and manipulation of the visual surround of the 727

  Generation of visible targets in positions commanded by the VAX

  Driving the four CRT's in the 727 cab

- A separate audio microprocessor controlled all communications.

Appendix F: SUBJECT INFORMATION FORM

NASA/FAA TCAS INFORMATION TRANSFER EXPERIMENT: SUBJECT INFORMATION

To our subjects:

As you know, we have guaranteed you absolute confidentiality, which means that we may not keep a record of your identity. Most of our subjects in the past, however, have asked to be informed of the results of the research in which they participated.

This form provides a way in which we may place your name on our mailing list without violating our pledge of confidentiality. By returning the form to us, you will be placed on our mailing list for TCAS reports, but we will not be able to match your name with the specific flights in which you were involved.

We are deeply grateful to you for taking part in this important study, and we hope you will enjoy being with us.

____
Sheryl L. Chappell, Principal Investigator

____
Barry C. Scott, Co-principal Investigator

(If desired, detach and mail this part of sheet)

Please place me on the mailing list for TCAS experiment reports:

____
NAME (please print)

____
STREET ADDRESS

____
CITY, STATE, ZIP

Appendix G: EXPERIMENTER CHECKLIST AND SUBJECT BRIEFING OUTLINE

DAY 1

Conditions 1, 2, 3, 4

____________	Administrative paperwork
____________	mailing list form
____________	meal selection
____________	dispatch papers
____________	safety briefing
____________	workload booklet

Conditions 2, 3, 4

____________	training film
____________	quiz
____________	flight manual supplement

DAY 2

Conditions 1, 2, 3, 4

____________	workload sheets 8x3
____________	questionnaire
____________	debrief
____________	experiment notebook
____________	encounter observer forms
____________	inop labels for TCAS panel

Conditions 1, 2, 3, 4

1. Please conduct the flight as you would normally; you should make cabin announcements, report out and off times, etc.
2. If you have any questions for maintenance or company operations, call them on company radio.
3. Expect normal occurrences, for example minor equipment problems.
4. We'll let you know if there is a computer or simulator problem.
5. Alternate legs: ____________ flies first today.
6. Cockpit activity is being monitored: flight data recorder and CVR.

Conditions 2, 3, 4

7. TCAS operation items have been added to your checklists.
8. Use the ground test to familiarize yourselves with the voice and lights.
9. If you have any question about the operation or interpretation of TCAS, a project pilot is always available through company radio.
10. Failure flags and their ramifications appear in the flight manual supplement.
11. Condition 3 only: Radar STBY is for radar, not TCAS.

Appendix H: QUIZ ON TCAS, USED DURING TRAINING

Note: Quiz shown is for Condition 4

Circle the letter corresponding to ALL answers which are correct.

1. TCAS will issue a traffic advisory for potential threat aircraft with:
   a. altitude reporting transponders
   b. transponders without altitude reporting
   c. no transponder

2. TCAS will advise you of a need for evasive action for threat aircraft with:
   a. no transponder
   b. transponders without altitude reporting
   c. altitude reporting transponders

3. When you see a red TCAS warning light and hear a siren and voice command, you should:
   a. refer to your IVSI lights which will tell you how not to maneuver
   b. refer to your IVSI lights which will tell you how to maneuver

4. When you receive a traffic advisory, you should:
   a. mentally and physically prepare for a possible maneuver
   b. promptly and smoothly maneuver your aircraft away from the threat
   c. attempt to establish visual contact with the threat aircraft

5. Order the following steps to be taken when TCAS recommends evasive action:
   ___ get the needle out of the lights
   ___ clear the airspace
   ___ return to your assigned altitude or flight path

6. You are climbing at 3000 fpm when the IVSI lights come on from -6000 to +1500 fpm, you should:
   a. check with ATC prior to adjusting your climb rate
   b. continue climbing at your present rate
   c. reduce climb rate to 1500 fpm to minimize deviation from clearance

7. When the IVSI designated a climb at 1500 fpm. You promptly established a 1500 fpm climb from level flight. When the IVSI lights go out except for 0 to -6000 fpm, you should:
   a. descend at a rate less than 1500 fpm to your previous altitude
   b. level your aircraft
   c. maintain 1500 fpm climb until all the lights are out and you hear "clear of conflict", then return to your previous altitude

Draw the following situations on the IVSI on the attached page:

8. Your descent rate is 1000 fpm and TCAS tells you not to exceed 1500 fpm descent.

   Is pilot action required? yes no

9. You are climbing at 3000 fpm, TCAS tells you to lessen your climb rate.

Is pilot action required? yes no

10. Your descent rate is 500 fpm and TCAS tells you to climb to avoid traffic:

Is pilot action required? yes no

11. You were level and now you are responding to a descend command:

12. The most important thing to remember about TCAS is:

Circle the letter corresponding to ALL answers which are correct.

13. When TCAS provides a resolution on the IVSI, the conflict traffic on the traffic display is a:
    a. white diamond
    b. red square
    c. amber circle

14. A threat aircraft that is beyond the range of the display is shown as:
    a. an unfilled white diamond
    b. an arrow in the direction of the threat
    c. an amber circle
    d. a data block in the upper left corner

15. Rank the following traffic symbols in the order of increasing threat:
    ___ red square
    ___ unfilled white diamond
    ___ filled white diamond
    ___ amber circle

16. The distance between your aircraft and the inner ring of tick marks is:
    a. 3 nautical miles
    b. selected on the display control panel
    c. 5 nautical miles
    d. shown in the upper right corner

17. This altitude block -09↑ indicates the traffic is ____________________

18. If a target has no altitude block:
    a. it is outside the altitude band you have selected for display
    b. it does not have an operating altitude encoder
    c. it is at your altitude
    d. TCAS can not issue a resolution maneuver

19. Does the selection of the above/below or horizontal range change the affectiveness of the TCAS? yes no

Appendix I: TCAS AIRPLANE FLIGHT MANUAL SUPPLEMENT

Note: Flight manual supplement shown here is for TCAS with continuous display of traffic, experimental condition 4.

AIRPLANE FLIGHT MANUAL SUPPLEMENT
FOR
BOEING 727

This Supplement must be attached to the FAA Approved Airplane Flight Manual if the Traffic Alert and Collision Avoidance System (TCAS) is installed. The information contained herein supplements or supersedes the information of the basic Airplane Flight Manual only in those areas listed herein. For limitations, procedures and performance information not contained in this Supplement, consult the basic Airplane Flight Manual.

TCAS Number 4

TABLE OF CONTENTS

TCAS Limitations

TCAS traffic advisory displayed information is for information only and is not to be used as a basis for maneuvering to avoid a threat aircraft.

COCKPIT PREPARATION

TRANSPONDER..STBY

ALTITUDE REPORTING..1, CMPR

TCAS...TEST

Select self-test and check for aural signals and indications on IVSI. On the traffic advisory display you will see: a heading of north, a 20 nautical mile horizontal range, the word TEST in the lower right corner, and each of the 4 target types, for 5 seconds. A failed self test is indicated by the amber TCAS FAIL flag on the IVSI, and the message FAIL preceded by the type of failure at the top of the traffic display.

NUMBER ONE FOR TAKEOFF

TRANSPONDER/TCAS

if passed TCAS self test.........................TCAS

if failed TCAS self test.......................XPDR 2

TCAS TRAFFIC ADVISORY PROCEDURE

MEMORY

TRAFFIC DISPLAY	OBSERVE	PF, PNF
VISUAL SEARCH FOR TRAFFIC	ACCOMPLISH	ALL

ALERT	INDICATIONS	PILOT RESPONSE
CAUTION	Tone, amber light (cancel if desired), amber circle at threat location on display	If threat traffic is visually acquired, maintain visual contact to insure separation

TCAS TRAFFIC CAUTION PROCEDURE, NO EVASIVE ACTION REQUIRED

MEMORY

IVSI NEEDLE OUT OF LIGHTS	VERIFY	PF, PNF
VISUAL SEARCH FOR TRAFFIC	ACCOMPLISH	ALL

ALERT	INDICATIONS	PILOT RESPONSE
CAUTION	IVSI lights, tone, amber lght, red square target on display	Monitor IVSI, keep needle out of amber lights. Continue visual search.

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TCAS TRAFFIC WARNING PROCEDURE, EVASIVE ACTION REQUIRED

MEMORY

IVSI LIGHTS	OBSERVE	PF, PNF
VISUALLY CLEAR AIRSPACE	ACCOMPLISH	PF, PNF
PITCH	ADJUST	PF
IVSI NEEDLE OUT OF LIGHTS	VERIFY	PF, PNF
VISUAL SEARCH FOR TRAFFIC	ACCOMPLISH	ALL
WHEN CLEAR, RETURN TO FLIGHT PATH	ACCOMPLISH	PF

ALERT	INDICATIONS	PILOT RESPONSE
CLIMB or CLIMB TO CROSS	IVSI lights $\leq$+2000 siren, voice "climb" red light, red square target on display	Promptly and smoothly establish a 2000 fpm climb, if climb rate >2000, maintain greater rate. Monitor IVSI for change in lights.
DESCEND or DESCEND TO CROSS	IVSI lights $\geq$-2000 siren, voice "descend", red light, red square target	Promptly and smoothly establish a 2000 fpm descent, if descent rate >2000, maintain greater rate. Monitor IVSI for change in lights.
ADJUST VERTICAL SPEED	IVSI lights for unsafe vertical rate siren, voice "adjust vertical speed", red light, red target	Promptly and smoothly adjust pitch to get rate needle out of lights. Monitor IVSI for change in lights.
CLEAR OF CONFLICT	no IVSI lights no siren/voice/light no red square target	Promptly and smoothly adjust pitch to return to last assigned altitude or flight path.
UNABLE TO COMMAND	IVSI lights flash siren, voice "unable to command", red light, red target	Use all available information to resolve traffic conflict.

FLIGHT INSTRUMENTS

TCAS FAILURE

If TCAS operation is erratic or unsatisfactory or if the TCAS FAIL flag appears and/or a failure message appears on the radar CRT:

TCAS/TRANSPONDER....................................XPDR 2

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TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS)

The Traffic Alert and Collision Avoidance System (TCAS) utilizes aural annunciation and warning lights to advise the pilots of threatening traffic as well as potentially threatening traffic. A caution & warning light, modified IVSI's and traffic advisory display serve as the system's indicators. A TCAS control panel is located on the forward electronics (control stand) panel.

BACKGROUND INFORMATION: The collision avoidance system (TCAS) will be operated in accordance with the procedures specified in this manual. This system only detects aircraft that are transponder equipped. Continued traffic vigilance is still necessary even with TCAS installed.

System Description

The Traffic Alert and Collision Avoidance System (TCAS) is a completely airborne system that interrogates transponders in nearby aircraft once each second. From these interrogations TCAS determines closure rate and predicts altitude separation at the closest point of approach (CPA). If TCAS computes that aircraft separation at CPA warrants notification of the crew, a traffic advisory will be issued.

A TRAFFIC ADVISORY provides information on the display to aid in visual acquisition of conflicting traffic.

If the conflicting traffic continues to close and TCAS determines the aircraft separation at CPA may cause the threat of a near-miss or possible collision situation, the system provides a caution or warning.

A TCAS CAUTION/WARNING provides the flight crew with vertical guidance and is displayed on the Captain's and First Officer's IVSI's. If separation is adequate, this vertical guidance will prevent the crew from initiating a climb or descent into the traffic. If separation is not sufficient, the warning will be guidance to alter the existing vertical flight path.

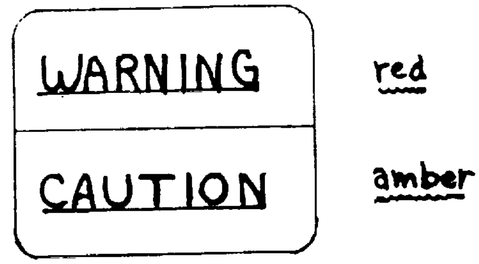
TCAS Control and Display System

The TCAS system provides a visual display of intruder aircraft, and both visual and audible warnings to the flight crew. The TCAS flight deck avionics display and control is divided into five subsystems:

1. TCAS control panel

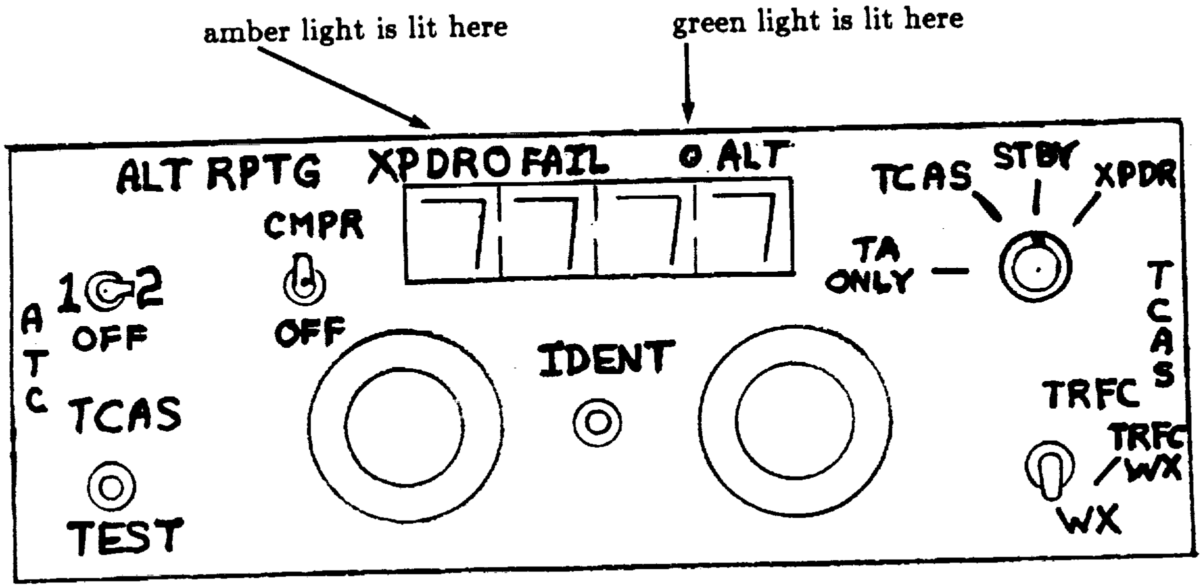
2. Traffic advisory display
3. Modified IVSI's for Captain & First Officer
4. TCAS CAUTION/WARNING Lights
5. TCAS audible warning system

Note: audible cautions and warnings are cancelled by pressing the warning light/switch.



TCAS CONTROL PANEL

This panel is located beside the radar CRT on the center console.



The function of each switch position is as follows:

STANDBY: TCAS is powered but display of information is inhibited.

XPDR1: Normal operation position for transponder and TCAS.

TCAS: Normal operation position for transponder and TCAS (Same as XPDR1).

XPDR2: Transponder 2, no TCAS.

TCAS TEST: Initiates the internal self-test procedure of TCAS components when transponder/TCAS in standby.

The two lights on the control panel indicate the operating status of the basic transponder & altitude reporting; the green light (indicated in control panel figure above) shows that the altitude reporting is not functioning; the amber light (also indicated in the control panel figure above) indicates a transponder failure.

TRAFFIC ADVISORY DISPLAY

The traffic advisory display provides TCAS information for interrogated transponder equipped aircraft. Aircraft position data are displayed as follows:

Own Aircraft - Represented by a aircraft symbol below center on the screen and pointed up.

Range Ring - The own aircraft symbol is encircled by 12 tick marks, at clock position 1 through 12. These tick marks are 3 nautical miles from own aircraft position and can be used to estimate range of conflicting traffic.
- A 5 mile range ring consists of a series of dots.

Intruder Aircraft - Presented by color coded symbols. Intruders outside the selected horizontal range are displayed as an arrow pointing to the aircraft's location. Color/shape coding of displayed information is as follows:

Amber Circle - Traffic advisory information. This traffic represents a possible threat. Visual search should be accomplished to locate this traffic.

Red Square - Traffic threat information. This traffic represents an actual threat. An IVSI displayed warning will be present for aircraft displayed in red.

White Diamond - A filled white diamond is used to represent any non-conflicting transponder equipped traffic within 4 miles, and ± 1,200 feet.
- An unfilled white diamond is used to represent any non-conflicting transponder equipped traffic within the selected horizontal and vertical ranges.

NOTE: Occasionally TCAS may not receive bearing information on an intruder for a short period of time. These aircraft will be represented in a table at the top of the display.

Intruder Relative Altitude - This information is displayed as a signed two digit number in hundreds of feet relative to own aircraft, plus for aircraft above and minus for aircraft below.

+05 (500 feet above)

Whenever the intruder is detected to be changing altitude at a rate of at least 500 FPM. An arrow will appear to the right of the altitude information to indicate a climb or descent.

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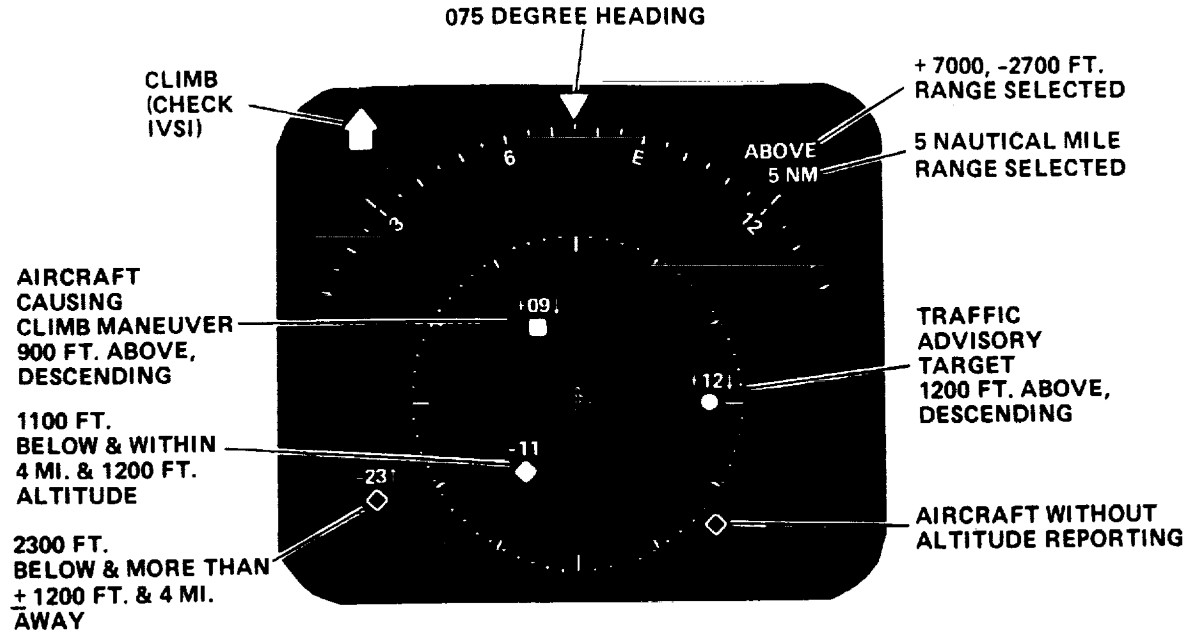
NOTE: Non-altitude reporting aircraft are displayed without an altitude data block.



TRAFFIC ADVISORY DISPLAY CONTROL PANEL

This panel is located beneath the traffic advisory display. The function of each switch position is as follows:

ALT FL -- This causes the altitudes of targets to appear as flight levels, rather than in hundreds of feet relative to you. This switch is spring loaded to the relative altitude (REL) position and the flight levels will revert to relative altitudes 15 seconds after depressing the switch.

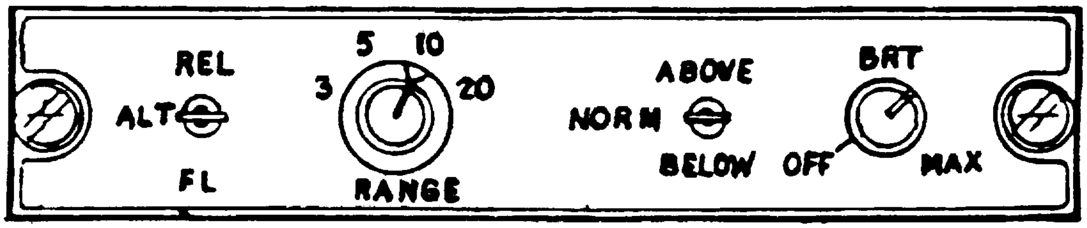
RANGE -- 3, 5, 10, and 20 nautical miles horizontal ranges may be selected at which traffic is seen. This number is reflected in the upper right corner of the traffic display.

ABOVE -- This switch selects the vertical range of traffic to be displayed. In the ABOVE position all traffic 7000 ft above and 2700 ft below will be shown..

NORM -- In the NORM position all traffic +/- 2700 ft will be shown.

BELOW - This switch selects the vertical range of traffic to be displayed. In the BELOW position all traffic 7000 ft below and 2700 ft above will be shown.

BRT - This knob adjusts the brightness of the display.



MODIFIED IVSI's

Segment lights have been added on the edge of the instrument face. When these lights illuminate, TCAS is advising the pilot that an aircraft vertical rate in the area illuminated is not appropriate. These segments are lighted to provide advisories to: climb, descend, not climb, not descent, to remain level or to limit aircraft vertical rate to 500, 1000 or 2000 feet per minute climb or descent.

CAUTION/WARNING LIGHTS

There is a caution/warning light mounted just below the glare shield. The light has an amber section marked "CAUTION" and a red section marked "WARNING." Depressing the light will extinguish the light and silence the aural warning system.

TCAS SPEAKER AND AURAL WARNING

The aural warning system provides selected aural indications (mono-tone or European siren) and voice instructions describing the vertical maneuver displayed on the IVSI. The TCAS speaker is mounted overhead in the cockpit.

OPERATION

Electrical power for the TCAS system comes from the master radio bus. To supply power to the TCAS select TCAS, XPDR 1, or STBY on the TCAS/transponder control panel.

TCAS DESIGN FEATURES WHICH LIMIT THE TCAS OPERATING ENVELOPE OR DISPLAYS

1. TCAS resolution maneuvers are not generated for non-altitude reporting aircraft.

2. TCAS does not detect non-transponder equipped aircraft.

3. TCAS maneuver indications are inhibited below 500 feet AGL.

4. TCAS maneuver indications are inhibited below 700 feet AGL when the landing gear is down and locked and the flaps are greater than 25 degrees.

> NOTE. When responding to a DESCEND advisory while in the landing configuration at low altitude, caution should be exercised. As with all TCAS advisories, visual acquisition should be attempted and all crews should remain altitude aware.

5. DESCEND advisories are inhibited below 700 feet AGL.

6. CLIMB advisories are inhibited whenever the landing gear is down and locked and the flaps are greater than 25 degrees.

7. TCAS receives radar altitude above ground level information from the radar altimeter. If the radar altimeter is inoperative, TCAS will indicate a failure message and the TCAS should be turned OFF by selecting transponder 2.

Warning Systems
B-727 Operations Manual Supplement

SYSTEM	CONDITION	WARNING
TCAS	TCAS TRAFFIC ADVISORY, POTENTIAL COLLISION THREAT	AMBER CAUTION LIGHT, TONE
	TCAS TRAFFIC CAUTION, COLLISION THREAT, NO MANEUVER REQUIRED	AMBER IVSI LIGHTS, AMBER CAUTION LIGHT, TONE
	TCAS TRAFFIC WARNING, COLLISION THREAT, EVASIVE MANEUVER REQUIRED	AMBER IVSI LIGHTS, RED CAUTION LIGHT, SIREN, AND A VOICE MESSAGE: "CLIMB, DESCEND, ADJUST VERTICAL SPEED, CLEAR OF CONFLICT, UNABLE TO COMMAND"

Appendix J: FORECAST AND ACTUAL WEATHER

Flight 712: SFO-SCK-LAX

WX CA-NV 1200Z-2400Z

BFL CLR 15 2512 54/46 989
FAT CLR 12 2305 52/42 989
LAX CLR 3H 2710 57/50 984 R25L OTS TO 1800Z
OAK 90 SCTD 10 2712 55/49 990
SCK -X3 BKN 1F 2210 60/59 987 R29VR5000
SFO 100 BKN 8 2615 57/49 990 R01L OTS UFN
SMF 90 BKN 4HK 2208 64/55 989

LAX CLR 5 BCMG CLR 2HK CHC 1F
SCK 50 BKN 5 CHC 10 OVCST 1F 2000Z 5 OVCST 1F
SFO CLR 15 OCNL 50 BKN 10 2000Z 50 BKN 10 BCMG 15 OVCST 5
SMF CLR 3 OCNL 50 BKN 2

CA-NV: WK LO 400 SW SFO MVG NE. BLCKG HI VCT LVS WL MV SE BY 1200Z TMRW.

CLDS,WX:
CSTL CA: CLR-BKN MDL CLD, VIS 5-10 THRU PD. INT VLYS CA: MDL CLD WL BCM LO CLDS AND FOG, CLD 05-10 BKN-OVCST VIS 2-3 OCNL BLO 1F. SO CAL: CLR 2-5HK OCNL 1-3HK. SFC WDS 22-26 10-15 THRU PD.

NOTAMS:
LAX: R25L OTS MTNCE TO 1800Z TODAY. TRKS AND PERS ON TAXIWYS SO OF R25R.
SFO: R01L OTS UFN DUE RESFCG.
SFO: R34 MALS OTS AFTER 0100Z TMRW. R34 GS OTS MTNCE.

Flight 713: LAX-SMF-SFO

WX CA-NV 1200Z-2400Z

BFL CLR 15 2512 50/46 989
FAT 9 OVCST 4F 0000 49/46 989
LAX CLR 3H 2710 57/50 984 R25L OTS TO 1800Z
OAK 90 SCTD 10 2712 55/49 990
SCK 4 BKN 11/2F 2210 60/59 987 R29VR6000+
SFO 110 BKN 8 2515 58/50 989 R01L OTS UFN
SMF 90 BKN 6 2210 64/55 989

LAX CLR 5 BCMG CLR 2HK CHC 1F
SCK 50 BKN 5 CHC 10 OVCST 1F 2000Z 5 OVCST 1F
SFO CLR 15 OCNL 50 BKN 10 2000Z 50 BKN 10 BCMG 15 OVCST 5
SMF CLR 3 OCNL 50 BKN 2

CA-NV: WK LO 400 SW SFO MVG NE. BLCKG HI VCT LVS WL MV SE BY 1200Z TMRW.

CLDS,WX:
CSTL CA: CLR-BKN MDL CLD, VIS 5-10 THRU PD. INT VLYS CA: MDL CLD WL BCM LO CLDS AND FOG, CLD 05-10 BKN-OVCST VIS 2-3 OCNL BLO 1F. SO CAL: CLR 2-5HK OCNL 1-3HK. SFC WDS 22-26 10-15 THRU PD.

NOTAMS:
LAX: R25L OTS MTNCE TO 1800Z TODAY. TRKS AND PERS ON TAXIWYS SO OF R25R.
SFO: R01L OTS UFN DUE RESFCG.
SMF: R34 MALS OTS AFTER 0100Z TMRW. R34 GS OTS MNTNCE.

Flight 716: SFO-SMF-LAX

WX CA-NV 0000Z-1800Z

BFL CLR 15 2512 54/46 989
FAT 9 OVCST 2F 0000 49/46 989
LAX 250 BKN 3HK 2706 55/50 985 R25L OTS TO 1800Z
OAK 90 SCTD 10 2712 55/49 990
SCK -X3 BKN 1F 2210 60/59 987 R29VR5000
SFO 90 BKN 12 2616 57/49 989 R01L OTS UFN
SMF 100 BKN 4HK 2212 62/55 988

LAX CLR 5 BCMG CLR 2HK CHC 1F
SCK 50 BKN 5 CHC 10 OVCST 1F 2000Z 5 OVCST 1F
SFO CLR 15 OCNL 50 BKN 10 2000Z 50 BKN 10 BCMG 15 OVCST 5
SMF CLR 3 OCNL 50 BKN 2

CA-NV: WK LO 400 SW SFO MVG NE. BLCKG HI VCT LVS WL MV SE BY 1200Z TMRW.

CLDS,WX:
CSTL CA: CLR-BKN MDL CLD, VIS 5-10 THRU PD. INT VLYS CA: MDL CLD WL BCM LO CLDS AND FOG, CLD 05-10 BKN-OVCST VIS 2-3 OCNL BLO 1F. SO CAL: CLR 2-5HK OCNL 1-3HK. SFC WDS 22-26 10-15 THRU PD.

NOTAMS:
LAX: R25L OTS MTNCE TO 1800Z TODAY. TRKS AND PERS ON TAXIWYS SO OF R25R.
SFO: R01L OTS UFN DUE RESFCG.
SMF: R34 MALS OTS AFTER 0100Z TMRW. R34 GS OTS MNTNCE.

Flight 715: LAX-SCK-SFO

WX CA-NV 0000Z-1800Z

BFL CLR 8 2410 52/46 989
FAT 7 OVCST 11/2F 2105 48/46 988
LAX 300 BKN 2HK 2704 55/50 985 R25L OTS TO 1800Z
OAK 80 BKN 15 2715 55/49 990
SCK 11 BKN 4F 2210 62/59 988
SFO 80 BKN 15 2714 56/49 989 R01L OTS UFN
SMF 90 BKN 3HK 2208 62/55 988

LAX CLR 5 BCMG CLR 2HK CHC 1F
SCK 50 BKN 5 CHC 10 OVCST 1F 2000Z 5 OVCST 1F
SFO CLR 15 OCNL 50 BKN 10 2000Z 50 BKN 10 BCMG 15 OVCST 5
SMF CLR 3 OCNL 50 BKN 2

CA-NV: WK LO 400 SW SFO MVG NE. BLCKG HI VCT LVS WL MV SE BY 1200Z TMRW.

CLDS,WX:
CSTL CA: CLR-BKN MDL CLD, VIS 5-10 THRU PD. INT VLYS CA: MDL CLD WL BCM LO CLDS AND FOG, CLD 05-10 BKN-OVCST VIS 2-3 OCNL BLO 1F. SO CAL: CLR 2-5HK OCNL 1-3HK. SFC WDS 22-26 10-15 THRU PD.

NOTAMS:
LAX: R25L OTS MTNCE TO 1800Z TODAY. TRKS AND PERS ON TAXIWYS SO OF R25R.
SFO: R01L OTS UFN DUE RESFCG.
SMF: R34 MALS OTS AFTER 0100Z TMRW. R34 GS OTS MNTNCE.

Appendix K: AIR TRAFFIC CONTROL SCRIPT

TCAS EXPERIMENT SCENARIO 6, SACRAMENTO TO LOS ANGELES

NOTE: In all scripts, normal communications from NASA aircraft are indicated. If unusual requests are received, controller should coordinate with experiment controller (ECON) prior to acting on request. ECON is on PBX ext. 25. Communications with other aircraft are indicated. Content of communications is given, but controllers are free to use their own phraseology, as long as they maintain consistency across experiments.

COMM. FREQUENCIES:

SMF ATIS:	126.75	ZLA HIGH SECTOR:	135.3
SMF CLEARANCE:	121.1	ZLA LOW SECTOR:	135.5
SMF GROUND CONTROL:	121.7	LAX APPROACH STL:	124.5
SMF TOWER:	125.7	LAX TOWER:	133.9
SMF DEPARTURE:	124.5	LAX GROUND CTL:	121.65
ZOA LOW SECTOR:	124.2	LAX ARRIVAL ATIS:	133.8
ZOA HIGH SECTOR:	132.8		

OTHER AIRCRAFT IN THIS SCENARIO:

UAL 893:	Taxiing and taking off ahead of ownship; parallels 716 to LAX
FT 061:	Descending to McClellan during ownship climb
PSA 552:	Northwest-bound at FL 240 above ownship at FROGO
SW 239:	Southwest on J-110 to RPI at FL 350
N 2PM:	Northeast on J-110 from RPI at FL 310
FOG 26:	Navy fighter climbing on J-65 southeast of RPI
AC 732:	Northwest-bound for Vancouver from LAX
N 267J:	Climbing west northwest of Santa Monica
N 456XX)	
N 328XX)	
N 165XX)	No comm traffic vicinity of Santa Monica and LAX
N 5XX)	
N 6XX)	
AIC 228:	727 departing runway 24L after 716 touches down

Sacramento Metropolitan Field ATIS: Sacramento Metro information Whiskey. Sacramento weather 6000 broken, visibility 4 miles, haze. Temperature 61, dewpoint 56, altimeter 29.88. Winds 230 at 14. Glide slope runway 34 out of service. Traffic landing and departing runway 16. Inform on initial contact that you have information Whiskey.

____ 716 is parked at gate 2, main terminal building.

____ 716 calls for clearance

SMFCLR: ____ 716, cleared to Los Angeles via the FROGO 5 departure, Friant, flight plan route. Maintain 7000, expect 330 after Thorne. Squawk 6534, departure on 124.5.

____ 716 calls for taxi

SMFGND: United 893, Tower at Alpha.

SMFGND: ____ 716, follow the 727 to runway 16, Tower at Alpha.

____ 716 calls for takeoff clearance

SMFTWR: ____ 716, you're number 2 for takeoff.

SMFTWR: United 893, cleared for takeoff runway 16. Straight out to 4000.

SMFTWR: ____ 716, position and hold runway 16 following United.

(When appropriate:)

SMFTWR: ____ 716, cleared for takeoff; observe the SID.

(When appropriate:)

SMFTWR: ____ 716, Departure now.

(After ____ 716 makes contact:)

SACDEP: ____ 716, radar contact, climb maintain 7000.

SACDEP: UAL 893, contact Oakland Center 124.2.

UAL893: Oakland Center, 124.2.

(When appropriate:)

SACDEP: ____ 716, Oakland on 124.2.

(After ____ 716 contacts:)

ZOA24L: ____ 716, climb maintain 17000.

ZOA24L: MAC 387, descend and maintain 7000, contact Sacramento Approach on 124.5.

M12387: Leaving ________ for 7000, Sacramento Approach on 124.5.

(Reference FT 61:)

ZOA24L: ____ 716, maintain 15,000; traffic 1 o'clock, 10 miles, out of 18,000 going to McClellan.

UAL893: (contact Oakland Center)

ZOA24L: UAL 893, climb maintain flight level 330.

UAL893: (Appropriate response)

ZOA24L: Tiger 61, traffic 10 o'clock, 9 miles, a 727 eastbound; he'll be at 15,000.

ZOA24L: UAL 893, contact Oakland Center on 132.8.

UAL893: (Appropriate response)

(When appropriate:)

ZOA24L: ____ 716, clear of traffic, climb maintain flight level 230, contact Oakland on 132.8.

(After ____ 716 contacts:)

ZOA15H: ____ 716, good evening. Climb maintain flight level 240.

(If ____ 716 requests direct, respond unable at this time)

PSA552: PSA 552 requesting lower.

ZOA15H: PSA 552, unable lower now; traffic at ______, lower shortly.

(When appropriate, call PSA 552 as traffic)

(After clear:)

ZOA15H: PSA 552, descend and maintain flight level 180.

PSA552: (Appropriate response)

ZOA15H: ____ 716, climb maintain flight level 330, direct Friant.

ZOA15H: PSA 552, contact Oakland Center 124.2.

PSA552: (Appropriate response)

(Approaching Friant, call SW 239 and N 2PM as traffic for each other, than call both as traffic for ____ 716)

(When ____ 716 is 27 miles south of Friant:)

OAK15H: Fog 26, maintain flight level 310.

(30 seconds later:)

OAK15H: Fog 26, Fog 26, if you read Center, maintain 310, right to 180 degrees...(pause)...Fog 26 on Guard, IMMEDIATE right turn to 180.

(time next so instruction for 716 too late:)

OAK15H: ____ 716, immediate left turn to 130.

(when appropriate:)

OAK15H: ____ 716, sorry about that; resume normal navigation direct DERBB.

OAK15H: Fog 26, contact Edwards radar, climb maintain flight level 450.

(when ____ 716 east of Avenal:)

OAK15H: ____ 716, contact Los Angeles on 135.3.

(after ____ 716 contacts:)

ZLA26H: ____ 716 at 330, roger.

AC 732: AC 732 leaving flight level ______ for FL 350.

ZLA26H: Roger AC 732.

(when ____ 716 at DERBB:)

ZLA26H: ____ 716, cleared for the Fillmore arrival to Los Angeles, profile descent at pilot's discretion to cross Fillmore at 16,000. Los Angeles altimeter 29.85.

(when appropriate:)

ZLA26H: ____ 716, Los Angeles 135.5.

(after ____ 716 contacts:)

LAX14L: ____ 716, roger; cross Fillmore at 15,000, Santa Monica at 7,000. You can delete the speed restriction.

(when ____ 716 passing 14,000 ft:)

LAX14L: ____ 716, traffic 11 o'clock, 9 miles, westbound, a Centurion climbing VFR, should be well below you.

LAX14L: Centurion 267J, traffic 1 o'clock, 7 miles, southbound descending to 15,000.

N 267J: 267J, looking.

LAX14L: ____ 716, show a light.

(during turn at SADDE:)

LAX14L: ____ 716, traffic 10 o'clock, 5 miles, eastbound, unconfirmed 7500 feet; Los Angeles Approach now 124.5.

(after ____ 716 contacts:)

LAXAPP: ____ 716, traffic 3 miles, eastbound, 7500 unverified, squawking VFR code. Numerous targets in the vicinity of Santa Monica. Cross Santa Monica at 7,000, maintain 5,000.

(when ____ 716 at Santa Monica:)

LAXAPP: ____ 716, left to 070, vectors to the 24 right final approach course. Descend to 5,000.

(when ____ 716 6 miles east of Santa Monica:)

LAXAPP: ____ 716, down to 4,000; turn in 3 miles.

(give fairly tight turn to 220 to intercept close to ROMEN:)

LAXAPP: ____ 716, right to 220, descend to 2200 feet, pick up the localizer, Tower 133.9 at ROMEN.

(after 716 contacts:)

LAXTWR: ____ 716, clear to land 24 right.

(on touchdown:)

LAXTWR: ____ 716, first high-speed, stay with me, hold short of the left. Air Cal 228, cleared for takeoff 24 left.

(when appropriate:)

LAXTWR: ____ 716, cross the left, ground point six five clearing.

LAXGND: 716, left on Uniform, taxi to your ramp.

LAX ARRIVAL ATIS: Los Angeles International Airport arrival information Victor. Los Angeles weather high thin broken, visibility 2, haze. Wind 210 degrees, 10 knots. Temperature 56, dew point 55, altimeter 29.85. Traffic landing and departing runways 24, 25. Inform Approach on initial contact that you have Victor.

Appendix L: ENCOUNTERS USED IN THE TCAS EXPERIMENT

Note: The encounters expected to produce TCAS traffic advisories and resolution advisories, together with some programmed visual proximate traffic inserted in the scenarios to enhance realism, are described here. It should be kept in mind that the outcome of each encounter depended upon several variables not under control of the experimenters, including ownship altitude rate, speed and in some cases, turn rate. Once generated, the conflict aircraft were deterministic: they followed precommanded instructions. They were generated when ownship passed a certain altitude, heading or geographical or navigational coordinate.

Flight Segment: San Francisco to Stockton

TA 01: Cruise at 11,000 ft

Light twin, mode C, level, 400 ft below, crossing left to right, announced by ATC.

Intended outcome: TA, no serious hazard

Proximate Traffic (PTFC): Descent, approaching ECA VOR

Military DC-9, ahead on long final approach, announced by ATC.

Intended outcome: Proximate traffic, no TA, no hazard

TA 02: Established on Approach, just above undercast

Light single, mode C, climbing toward, then above, ownship, right to left, announced only to aircraft ahead on approach

Intended outcome: TA, poorly visible, moderate hazard

Flight Segment: Stockton to Los Angeles

TA 03: Initial climb, emerging from low cloud

Light aircraft, nearly headon, mode A, level flight above ownship, announced by ATC, usually fairly close when observable

Intended outcome: TA, visible only when fairly close, moderate hazard

PTFC: Beginning descent after passing AVE VOR

HS-146 ahead and below ownship, same route, slower in descent, announced by ATC; ATC separation provided

Intended outcome: Proximate traffic only, no TA

TA 04 (RA): Descent inside SMO, SCK-LAX

Light aircraft, left to right, nearly head-on, 100' below altitude to which ownship is cleared, passes slightly to right and slightly below if ownship levels precisely; mode C; visibility relatively poor; unannounced by ATC

Intended outcome: RA, limited time to react; severe hazard

TA 05: Turning to final approach, SCK-LAX

Small jet, ahead on approach in trail, announced by ATC; visibility 4 miles

Intended outcome: TA, no hazard

PTFC: Turning to final approach, SCK-LAX

Jet transport, slightly ahead on approach to parallel runway, not announced

Intended outcome: Proximate traffic, no hazard (TA if ILS course is overshot)

Flight Segment: Los Angeles to Sacramento

TA 06: Climbing below 10,000 to GMN VOR

Light twin, nearly own direction, level, much slower; ownship passes above; announced by ATC as one of several targets (two visible, nearly in line)

Intended outcome: TA, visible well ahead, no hazard if climb rate maintained

TA 07: Reaching 10,000 in climb

Large turboprop, descending toward Point Mogu, crossing right to left; announced; ownship held below target by ATC; target clearly visible

Intended outcome: TA, visible, no hazard unless restriction is missed

TA 08 (RA): Rapid descent below 10,000 on downwind, LAX-SMF

Light twin, fast, below, left to right, nearly head-on, descending more slowly than ownship; mode C, announced before becoming visible; difficult to evaluate relative motion

Intended outcome: RA, moderate or severe hazard

TA 09: Turning to base leg, then to final approach at SMF

Light aircraft, mode C, crossing localizer course at outer marker from left to right on first contact; visible; depending on ownship turns, may be a problem twice, though 500-700 ft below; not announced by ATC

Intended outcome: TA once or twice, no hazard unless ownship descends early

---

Flight Segment: Sacramento to San Francisco

TA 10 (RA): Descending on visual approach to SFO

Light aircraft, mode C, left to right passing level below ownship in descent; probable RA if ownship follows descent profile correctly; good visibility, but traffic is observed against many ground lights

Intended outcome: TA, often RA, moderate hazard

PTFC: On visual approach to SFO

Transport, descending and convergin from left; passes well above ownship enroute to OAK

Intended outcome: Proximate traffic only, no hazard

TA 11: On final approach at outer marker

Light aircraft, mode A, 400 ft below passing left to right, unannounced

Intended outcome: TA or proximate traffic, no hazard but distracting

---

Flight Segment: San Francisco to Sacramento

TA 12: On standard instrument departure below 10,000 ft

Light twin, head-on, 9500', mode C, above TCA; ownship climbing to 11,000, target clearly visible, announced by ATC but not communicating

Intended outcome: Depends on climb rate. Probable TA, possible RA, minimal hazard.

PTFC: On standard instrument departure below 10,000 ft

Jet traffic descending through 10,000, crossing left to right enroute to Oakland; at normal climb rate, ownship should be well above (one of two aircraft visible at this point in climb)

Intended outcome: Proximate traffic only, no hazard

Flight Segment: Sacramento to Los Angeles

TA 13: During enroute climb, passing 17,000 ft

Military jet transport, crossing right to left in slow descent, passes about 1300 ft below ownship; ATC announcement and separation if required

Intended outcome: Proximate traffic only, no hazard unless slow climb rate

PTFC: During enroute climb, passing 21,000 ft, joining airway

Jet, opposite direction on airway, 25,000 ft. ATC separates aircraft, clears ownship for climb after passing

Intended outcome: Proximate traffic only, no hazard

PTFC: In cruise at 33,000 ft, passing FRA VOR

Two jet aircraft, one 2000 ft above left to right, the other 2000 ft below, right to left, on J-110; both announced by ATC

Intended outcome: Proximate traffic only, no hazard unless ownship not yet at cruising altitude (this occurred in one instance)

TA 14 (RA): In cruise, 30 miles south of FRA VOR

Military fighter converging on ownship from right and behind; very fast, climbing at high rate through ownship altitude with radio failure. Climb terminates just below ownship altitude. Announced by ATC; ATC unable to resolve problem by stopping climb.

Intended outcome: Resolution advisory or possible TCAS Invalid; serious hazard.

TA 15: During descent into terminal area passing 11,000 ft

Light twin, climbing and passing left to right, crosses 400-500 ft above ownship if descent maintained; not announced by ATC; clearly visible

Intended outcome: TA, possible RA; moderate hazard

TA 16: During descent to SMO VOR, passing 8000 ft

Light aircraft to left, overtaken by ownship. Mode C, announced by ATC; level 7500 ft, ownship cleared to cross SMO at 7000 ft

Intended outcome: TA, often visible, minimal hazard

Flight Segment: Los Angeles to Stockton

TA 17 (RA): In cruise flight at 31,000 ft approaching RPI VOR

In instrument conditions; small jet descending from right to left at high descent rate; ATC preoccupied with military refueling exercise loses track of separation. Target crosses ownship slightly ahead, passes 200 ft below ownship. Cannot be detected without TCAS.

Intended outcome: Resolution advisory, probably crossing; severe hazard

PTFC: In descent to Stockton

Jet aircraft, ahead; ownship overtaking; ATC provides separation.

Intended outcome: Proximate traffic only, no hazard

TA 18: Established on final approach to Stockton

Light aircraft, no transponder, crossing ILS course at outer marker; poorly visible because of fog, 300-400 ft above ownship; not announced by ATC

Intended outcome: TCAS cannot provide warning; visual separation only, moderate hazard

PTFC: On final approach to Stockton

Jet aircraft, 5 miles ahead on final approach, announced by ATC; not visible because of low cloud and fog

Intended outcome: Proximate traffic only; no hazard

Flight Segment: Stockton to San Francisco

TA 19: On departure from Stockton, passing 2000 ft

Light aircraft, left to right at 2700 ft, level; becomes visible; mode A; announced by ATC shortly after takeoff as "altitude unknown"

Intended outcome: TA only (mode A); moderate hazard

TA 20 (RA): In cruise at 10,000 ft TA 21: "

TA 20, large jet in descent with electrical problem, cleared to 11,000 ft; does not terminate descent at 11,000, passes left to right ahead of ownship in close proximity. Announced by ATC with TA 21.

TA 21: light turboprop, level at 9500 ft, almost head-on, opposite direction; clearly visible but blocks ownship descent reference TA 20.

Intended outcome: Resolution advisory, possible TCAS Invalid; severe hazard reference TA

20, no hazard reference TA 21

TA 22: In descent for visual approach at San Francisco

Military fighter descending, crossing left to right toward Alameda NAS; slightly faster, overtakes but passes well below ownship; announced by ATC; no separation required.

Intended outcome: Proximate traffic or TA; no hazard

TA 23: Approaching outer marker at San Francisco

Air carrier 727 ahead to left, approaching left runway (ownship cleared for approach to right). Announced by ATC, separation provided if necessary. Target declares missed approach below 1000 ft, continues straight ahead in climb.

Intended outcome: Proximate traffic, same direction, TA only if ATC permits ownship to get too close.

Appendix M: DATA FORMS USED BY OBSERVERS

EXPERIMENT OBSERVER FORM

(Fill out for each conflict)

Date:

TCAS mode:

Crew number:

Start at SFO / LAX

Lighting conditions: twilight / night

Origin & destination:

Leg sequence:

Flying: Capt / First Officer

Time:

Video tape number:

Intruder ID:

TA / RA

Altitude crossing: yes / no

Visual contact: yes / no

Conflict with clearance: yes / no

Aircraft configuration: ______________

ATC traffic advisory: yes / no

ANALYSIS OF EACH RESOLUTION ADVISORY

1) ________________ Run number
2) ________________ Capt or F/O flying

Type of RA

3) ________________ RA sequencial number for crew
4) ________________ RA sequencial number for pilot
5) ________________ Tail/flight number of intruder
6) ________________ Type of RA
________________ corrective / preventive
7) ________________ Altitude crossing RA
8) ________________ Meteorological conditions
9) ________________ Visual acquisition
10) ________________ ATC advisory on intruder

Pilot Response

11) ________________ Manual vs. autopilot response
12) ________________ time of TA
13) ________________ time of RA
14) ________________ altitude at RA
15) ________________ time of change in stick or throttle position
16) ________________ Time attained commanded vertical speed (1500 clb/desc)
17) ________________ vertical speed at max deviation during RA
18) ________________ altitude at max deviation during RA
19) ________________ time of RA off
20) ________________ altitude at RA off
21) ________________ time to initiate return to altitude at RA off
22) ________________ Maximum vert speed after RA off if > during RA
23) ________________ altitude at max deviation after RA off if > during RA
24) ________________ Time to return to RA altitude*
25) ________________ heading change if >10 degrees +/- right/left
26) ________________ max bank if heading change >10 deg
27) ________________ TA altitude if climbed/descended on TA

Achieved Separation

28) ________________ Minimum slant range of intruder
29) ________________ Time of minimum slant range
30) ________________ Vertical miss distance at min range
31) ________________ Horizontal miss distance at min range

*use altitude at TA if pilot maneuvered on TA
use the altitude +/- 300 feet when had been level
use the vertical speed just before the maneuver if climbing/descending

Appendix N: WORKLOAD RATING SCALES

Note: The workload rating instrument used in this study was the NASA Task Load Index (TLX), Version 1.0, provided by the Human Performance Research Group at NASA-Ames Research Center. Extracts from the test booklet are shown in the following pages:

Rating scale definitions, shown and briefed to flight crews during the instruction period on the day before the experiment.

A sample rating sheet. One of these sheets was completed by each flight crew member after arrival at blocks following each flight segment.

The workload comparison sheet, filled out by each flight crew member prior to debriefing after the final flight of the day. Each crew member was asked to choose between the dimensions shown in each comparison.

Subject ID: ______________ Task ID: ____________________

RATING SHEET

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Good Poor

EFFORT

Low High

FRUSTRATION

Low High

RATING SCALE DEFINITIONS

TITLE	ENDPOINTS	DEFINITIONS
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g., thinking deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION	LOW/HIGH	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

WORKLOAD COMPARISON

EFFORT OR PERFORMANCE	TEMPORAL DEMAND OR FRUSTRATION	TEPMORAL DEMAND OR EFFORT	PHYSICAL DEMAND OR FRUSTRATION
PERFORMANCE OR FRUSTRATION	PHYSICAL DEMAND OR TEMPORAL DEMAND	PHYSICAL DEMAND OR PERFORMANCE	TEMPORAL DEMAND OR MENTAL DEMAND
FRUSTRATION OR EFFORT	PERFORMANCE OR MENTAL DEMAND	PERFORMANCE OR TEMPORAL DEMAND	MENTAL DEMAND OR EFFORT
MENTAL DEMAND OR PHYSICAL DEMAND	EFFORT OR PHYSICAL DEMAND	FRUSTRATION OR MENTAL DEMAND	

CIRCLE THE WORKLOAD DIMENSION THAT REPRESENTS THE MORE IMPORTANT CONTRIBUTOR TO WORKLOAD FOR THE SPECIFIC TASK(S) YOU PERFORMED IN THIS STUDY.

Appendix O: TCAS POST-FLIGHT QUESTIONNAIRES

Note: Questionnaires appropriate to the TCAS Condition experienced were filled out by all crew members during their debriefing sessions. Though some questions differed, most questions were presented to all TCAS-equipped crews (conditions 2, 3, 4). A shorter questionnaire was presented to non-TCAS crews.

Post-Flight Questionnaire for the NASA/FAA TCAS Human Factors Study

Now that you have this simulation we would like to get your evaluation of the system and its use. Remember this research will provide input to the ultimate design and implementation of the TCAS which will eventually be in your airplane. It is very important that you carefully answer each question. Generally it is best to record the response that first comes to mind.

This questionnaire is meant to be a starting point for your evaluation, don't limit your responses to these questions. Use the reverse sides of the pages to expand and extrapolate from these issues.

Please mark the point on the scale best representing your evaluation of the following items.

Crew Member: Capt F/O S/O

In comparing this simulation to typical line flights:

1. The cockpit procedures and duties in this simulation were:
very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic

2. The air traffic control services in this simulation were:
very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic

3. The aircraft response to manual control input was:
very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic

4. The differences between the aircraft you fly and this simulator were:
very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting

5. How often were you aware of the location of known traffic?

never |___|___|___|___|___|___|___|___|___|___| always

6. The information from ATC traffic advisories and seeing the aircraft out of the window was:
often conflicting |___|___|___|___|___|___|___|___|___|___| never conflicting

7. Did you ever take evasive action to avoid another aircraft? yes no

8. What type of evasive maneuver do you prefer?
no preference climbs/descents turns

9. What are your current procedures for ATC traffic advisories and see-and-avoid? ______________________________

____

____

10. What ways could the air traffic controller better help you to avoid near mid air collisions? ______________________________

____

____

11. Based upon your actual flight experience does a collision threat exist?

strongly disagree |___|___|___|___|___|___|___|___|___|___| strongly agree

Questions Concerning the use of the TCAS:

12. For the purpose of operating TCAS, your understanding of the operation and limitations of TCAS is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete

13. For the purpose of operating TCAS, your understanding of the TCAS traffic advisory is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete

14. For the purpose of operating TCAS, your understanding of the TCAS maneuver advisory is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete

15. The training you received for TCAS use was:

very inadequate |___|___|___|___|___|___|___|___|___|___| very adequate

16. The operational procedures for TCAS use were:

very inappropriate |___|___|___|___|___|___|___|___|___|___| very appropriate

17. The addition of TCAS to the other flight duties was:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting

18. After several months of use in line service TCAS would be:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting

19. For reducing the risk of mid-air collisions, TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

20. For aiding visual contact with the traffic, TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

21. Would TCAS affect the time you normally spend scanning for traffic?

increase scan time |___|___|___|___|___|___|___|___|___|___| decrease scan time

22. The information from ATC traffic advisories and the TCAS was:

often conflicting |___|___|___|___|___|___|___|___|___|___| never conflicting

23. Would TCAS increase or decrease contact with ATC?

greatly increase |___|___|___|___|___|___|___|___|___|___| greatly decrease

24. In rare instances TCAS is unable to recommend a resolution ("Unable to Command"), given this limitation, do you feel TCAS is an acceptable system for reducing the risk of mid-air collisions?

very unacceptable |___|___|___|___|___|___|___|___|___|___| very acceptable

25. What did you do when this occured? ________________________________

____

26. Was the aural alert and caution/warning light effective in getting your attention?

very ineffective |___|___|___|___|___|___|___|___|___|___| very effective

27. Was the aural alert and caution/warning light distracting in their function of getting your attention?

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting

28. In preparing for evasive maneuvers, the TCAS traffic advisory was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

29. In executing TCAS evasive maneuvers, the voice command was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

30. For communicating the recommended evasive action or restriction to vertical rate, the lights on the IVSI were:

difficult to interpret |___|___|___|___|___|___|___|___|___|___| easy to interpret

31. The average time it took you to initiate the evasive maneuver, after the TCAS warning, was ________ seconds.

32. The evasive maneuvers as prescribed by TCAS were:

very unacceptable |___|___|___|___|___|___|___|___|___|___| very acceptable

33. The IVSI indications of unsafe vertical rates (when evasive action was not required) were:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

34. Did you ever take evasive action without being told to by TCAS? yes no

if so, did you do so based on visual contact with the traffic? yes no

35. Did you ever maneuver differently than TCAS instructed? yes no

36. If so, please explain ______________________________

____

37. Were you reluctant to perform a TCAS maneuver that required you to cross through another aircraft's altitude?

very reluctant |___|___|___|___|___|___|___|___|___|___| not at all reluctant

38. Were you reluctant to perform a TCAS maneuver in conflict with your ATC clearance?

very reluctant |___|___|___|___|___|___|___|___|___|___| not at all reluctant

39. Would you be reluctant to maneuver in conflict with your ATC clearance if the rules were changed so that TCAS evasive action was endorsed?

very reluctant |___|___|___|___|___|___|___|___|___|___| not at all reluctant

40. Were you reluctant to perform a TCAS maneuver in IMC?

very reluctant |___|___|___|___|___|___|___|___|___|___| not at all reluctant

41. Operation of TCAS in IMC and VMC was:

very different |___|___|___|___|___|___|___|___|___|___| not at all different

Please explain: ______________________________

42. Would you be satisfied with this TCAS system as a safety enhancement to the airplane you fly?

greatly dissatisfied |___|___|___|___|___|___|___|___|___|___| greatly satisfied

43. Were there instances where the TCAS did not perform as you expected it to?

Please explain: ______________________________

____

44. Were inappropriate maneuvers prescribed? Please explain:

____

____

45. How often did you contact ATC regarding traffic conflicts identified by TCAS?

always |___|___|___|___|___|___|___|___|___|___| never

46. What changes would be appropriate in pilot and controller operating procedures with the implementation of TCAS? ____________________

____

____

47. What is the feature you liked most about TCAS? ____________________

____

____

____

48. What is the feature you liked least about TCAS? ____________________

____

____

____

Questions Concerning the Information on the Traffic Advisory Display:

49. In general, the traffic information was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

50. The information on the display was:

not ay all legible |___|___|___|___|___|___|___|___|___|___| very legible

51. Interpreting the information on the display was:

difficult to interpret |___|___|___|___|___|___|___|___|___|___| easy to interpret

52. Were the different colors and symbol shapes of targets helpful in recognizing threats?

not at all helpful |___|___|___|___|___|___|___|___|___|___| very helpful

52a. Were the different colors of targets helpful in recognizing threats?

not at all helpful |___|___|___|___|___|___|___|___|___|___|___| very helpful

53. The number of targets on the display was:

too few |___|___|___|___|___|___|___|___|___|___|___| too many

54. The maximum number of targets seen on the display at one time was? _____

55. Additional filtering of targets (either manual or automatic) would be:

very undesirable |___|___|___|___|___|___|___|___|___|___|___| very desirable

56. The 3 and 5 mile fixed range rings on the display were:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

56a. The 2 mile fixed range ring on the display was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

57. What value of fixed range rings would you substitute or add? _______

58. The horizontal/vertical range you generally used for departure and climb was _______/_______, for cruise _______/_______, for descent _______/_______, for approach _______/_______.

59. Being able to vary the horizontal range for targets to be displayed was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

In what way?____

59a.Being able to vary the horzontal range for targets to be displayed would be

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

61. Being able to vary the vertical range for targets to be displayed was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

In what way? ____

61a. Being able to vary the vertical range for targets to be displayed would be:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

63. Would you prefer a system that automatically switched horizontal and vertical ranges? yes no

64. The location of the display was:

very poor |___|___|___|___|___|___|___|___|___|___|___| very good

64a. Pushing the traffic switch to display the 8 most important targets being tracked by TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

64b. Could the triangle symbol at the other aircraft's location be omitted and the data block adequately represent its location? yes no

65. How often did you use the arrows to determine if traffic was climbing or descending?

never |___|___|___|___|___|___|___|___|___|___|___| often

66. Did the traffic display ever cause you to expect a climb when TCAS told you to descend, or vice versa? yes no

67. Please explain: ______________________________

____

68. In executing evasive maneuvers, the symbol for the type of maneuver in the upper left corner was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

69. The refresh rate of the displayed location of the traffic was:

very unacceptable |___|___|___|___|___|___|___|___|___|___|___| very acceptable

70. The location of the traffic as represented on the display differed from what was observed out of the window:

often |___|___|___|___|___|___|___|___|___|___|___| never

71. Would the traffic advisory display help prevent being startled by the presence of the nearby aircraft on a parallel approach? yes no

72. The addition of the traffic advisory display to the cockpit was:

very distracting |___|___|___|___|___|___|___|___|___|___|___| not at all distracting

73. Did the traffic advisory display provide confidence in the correctness of the subsequent maneuver advisory? yes no

74. Do you feel the information on the traffic advisory display is accurate enough to be used to maneuver your aircraft? yes no

Please explain: ______________________________

____

75. Did you ever maneuver without being told to by TCAS based on the information on the traffic advisory display? yes no

76. Were there features of the display that interfered with your use of the TCAS? yes no

Please explain ____

____

____

77. Your understanding of the operation of the traffic advisory display is:

very limited |____|____|____|____|____|____|____|____|____|____| very complete

78. The training you received on the traffic advisory display was:

very inadequate |____|____|____|____|____|____|____|____|____|____| very adequate

79. Would you add any information to the traffic advisory display? yes no

If so what? ____

____

____

80. What information would you take off of the traffic advisory display?

____

____

____

Appendix P: VERBAL DEBRIEFING OF SUBECTS

Scenario number ____________ **Date** ________________

Notes for flight crews:

There was an exaggerated number of TCAS encounters in this experiment so that we could get sufficient data.

Please don't discuss this experiment with anyone until March when we will release the data.

We will send you the final report if you return the mailing list forms.

There will be no association of data with your airline or the individual pilots.

Comments by flight crew members:

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Appendix Q: HUMAN FACTORS OF THE TCAS II COLLISION-AVOIDANCE SYSTEM: MANEUVERS BASED ON RESOLUTION ALERTS

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March, 1988

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HUMAN FACTORS OF THE TCAS II COLLISION-AVOIDANCE SYSTEM: MANEUVERS BASED ON RESOLUTION ALERTS

INTRODUCTION

The overburdened United States air traffic control system has failed to prevent a significant number of near midair collisions during the last few years. The increase in air traffic due to airline deregulation has saturated the current air traffic control system and has spurred the development of practical airborne collision avoidance systems.

Three levels of collision avoidance system have been proposed for use in U. S. national airspace. "TCAS" is an abbreviation for "Traffic Alert and Collision Avoidance System". The major difference between the three systems, other than cost, is the amount and type of collision avoidance maneuver information that is provided to the pilot. The TCAS I system provides no avoidance maneuver commands, while the TCAS II system directs evasive maneuvers in the vertical plane only (climbs and descents). The TCAS III system provides turns in addition to climbs and descents. The major disadvantage of all three systems is that the intruder aircraft must be transponder equipped in order to be tracked by the TCAS system. Additionally, for a TCAS II or TCAS III equipped aircraft to receive collision avoidance commands, the intruder aircraft must have a mode C (altitude reporting) transponder.

This report describes the effect of corrective resolution advisories on separation between conflicting aircraft. Information obtained from a NASA-Ames simulation using airline flight crews and a Boeing 727 flight simulator was examined and analyzed to determine the effect on vertical and slant-range separation of maneuvers conducted in response to maneuver advisories generated by TCAS II.

The research was conducted under the Navy-NASA Joint Institute of Aeronautics Program. Analysis of the data was completed using the facilities of the NASA-Ames Research Center and the Naval Postgraduate School.

TCAS II SYSTEM DESCRIPTION

TCAS II is a self-contained system designed to preserve ATC vertical separation by tracking aircraft, evaluating collision potential, and displaying advisories and warnings. The warnings include recommended evasive maneuvers in the vertical plane. The system computes the range, relative altitude, and bearing of nearby aircraft by interrogating their transponders and evaluating the replies.

The traffic's relative altitude and position information is displayed by color coded symbols on a traffic display (Vol. I, Fig. 1). Display characteristics differ among the airlines. The traffic advisory display covers an area at least six NM ahead of the aircraft to three NM behind the aircraft. Intruder aircraft are colored amber unless they pose a collision threat within 20 to 30 seconds. If the intruder aircraft is determined to be a threat, the TCAS computer changes the color of the symbol to red, and activates warning tones, a warning voice, and red lights on the glareshield. These warnings direct the pilot's attention to the resolution advisory (RA) display which displays recommended evasive action.

The RA display is an IVSI (Instantaneous Vertical Speed Indicator) which has been modified with red "eyebrow" lights around the circumference to indicate whether a climb or descent is required to increase separation distance. The warning lights will extinguish, and a voice will state "clear of conflict" when the collision threat no longer exists. Installation of the system requires the addition of an antenna on top of the fuselage, a computer unit (black box) and a mode S transponder. If two conflicting aircraft are equipped with the TCAS II system, collision avoidance maneuvers will be coordinated automatically by their respective TCAS computer units through the mode S transponder data link.

MANEUVERS BASED ON RESOLUTION ADVISORIES OR ALERTS

Introduction

The TCAS II Resolution Advisory (RA) warning consists of an aural tone and a red warning light on the glareshield. These warnings direct the pilot's attention to the resolution advisory display (modified IVSI). The red "eyebrow" lights on the instrument will illuminate directing the pilot to modify the aircraft's vertical speed to "keep the IVSI needle out of the red". Simultaneously, a computer generated voice will suggest a course of action to the flight crew. The voice commands used in this study were: **"climb"**; **"climb to cross"**; **"adjust vertical speed"**; **"descend"**; **"descend to cross"**; **"clear of conflict"**; and **"unable to command"**.

These commands are given assuming the pilot does not have visual contact with the conflicting aircraft. If visual contact with the other aircraft is gained, the pilot may elect to maneuver using his own judgment to avoid the conflicting traffic. Flight crew responses depend on the prior training they have received.

Two types of resolution advisories are issued. A **preventive resolution advisory** requires no immediate action but warns the crew not to climb, descend, or adjust vertical speed due to nearby traffic. A **corrective resolution advisory** directs the pilot to alter the vertical speed of the aircraft to ensure safe separation from nearby traffic in the vertical plane.

The goal of the TCAS II system is to produce safe vertical separation between aircraft by signaling for a smooth, controlled adjustment of the TCAS aircraft's vertical speed until clear of the conflicting traffic.

This report examines the effectiveness of the TCAS II resolution advisory display for 40 encounters. The encounters involved crews using various versions of the TCAS II system while flying a Boeing 727 simulator in a simulated air traffic environment at the NASA-Ames Research Center.

Only corrective resolution advisories are examined in this report.

Procedures

An airborne collision avoidance system is only effective if the flight crews using the system are adequately trained to use the system to increase the vertical separation between aircraft.

An increase in vertical separation also results in an increase in slant range (i.e. miss distance) at the closest point of approach (CPA) between the TCAS equipped aircraft and the conflicting traffic. In order to determine the effectiveness of pilot responses to resolution alerts, 12 airline crews flew short routes in a simulated air traffic environment with numerous traffic conflicts. Forty encounters were examined in which the crews were required to perform evasive maneuvers based on TCAS warnings on the resolution advisory display. For each encounter, the following parameters were computed and examined:

(1) The amount of time between the traffic advisory (TA) and the closest point of approach (CPA) between the TCAS equipped aircraft and the conflicting aircraft.

(2) The amount of time between the resolution alert (RA) and the CPA for the two aircraft.

(3) The amount of time between the TA and RA. This is the amount of time the crew had to examine the potential conflict and prepare for the evasive maneuver.

(4) The vertical separation between the two aircraft at CPA after performing the collision avoidance maneuver.

(5) The slant range (miss distance) between the two aircraft at CPA after performing the recommended evasive maneuver.

These results were obtained using computer records which contained raw data on the following parameters: RA and TA on and off times; latitude and longitude readouts for both the TCAS aircraft and the conflicting aircraft; and altitude readouts for both aircraft.

A computer program was written to evaluate these raw data. Additional records detailing the encounters included observer records and resolution advisory analysis forms. Video tapes of the flight station of the Boeing 727 simulator were viewed to determine Air Traffic Control (ATC) clearance requirements, required level off altitudes, and flight crew responses.

In addition to the five results listed above, additional computations were made to determine the flight path the aircraft would have flown if it were not TCAS equipped. This flight path was based on the assumption that the crew did not obtain a visual sighting of the conflicting aircraft and therefore did not maneuver to avoid it.

Additional assumptions included the following: the crew would fly the same track over the ground; the crew would comply with all required ATC turns and navigation turns; and the crew would comply with all level off restrictions required by ATC. These assumptions are considered reasonable since the TCAS II system directs evasive maneuvers in the vertical plane only, and the altitude of the TCAS aircraft during each scenario is of primary concern.

For each scenario, the altitude of the TCAS aircraft was modified in the computer program to account for the descent or climb rate in progress before the evasive maneuver occurred. The TCAS aircraft's vertical rate was calculated beginning five seconds prior to the resolution alert. The program accounted for level off clearances and maneuvers that occurred on the traffic advisory display information. The TCAS aircraft altitudes were incrementally calculated, beginning one second after the RA occurred, until CPA or a level off altitude was reached. The same five results that were listed previously for the TCAS maneuver were then determined for the case where no TCAS maneuver was performed. The differences between the vertical separation and slant range at CPA were compared for the TCAS maneuver case and the no maneuver case.

Several corrective resolution alerts in the NASA-Ames study could not be examined due to a problem with the data files containing the conflicting aircraft's position and altitude information. The system could only record data on two aircraft at one time.

Results

A summary of the data for the 40 encounters is contained in Table 1. It lists the following information for each encounter: the time interval between the traffic alert (TA) and CPA; the time interval between the resolution alert (RA) and CPA; the time interval between the TA and RA; the altitude difference between the TCAS aircraft and the conflicting aircraft at CPA; the altitude difference at CPA between the two aircraft that would have occurred assuming the TCAS collision avoidance maneuver had not been performed (no TCAS maneuver case); the altitude separation difference between the TCAS maneuver and no TCAS maneuver scenarios; and the slant range difference between the TCAS maneuver and no TCAS maneuver scenarios.

The time interval between the issuance of a traffic advisory (TA) to the crew and time of CPA of the two aircraft represents the amount of time available for the crew to evaluate the situation and react appropriately if a RA display had not been installed. Several crews in the study were able to predict the occurrence of some of the resolution alerts by observing potential collision situations developing on the traffic advisory display. The average time interval between the TA and CPA was 39.25 seconds with a sample standard deviation of 12.03.

The time interval between the issuance of a resolution alert (RA) to the crew and the time of CPA of the two aircraft represents the amount of time available for the crew to interpret the information on the RA display and react by maneuvering the aircraft prior to CPA. The average time interval was 23.03 seconds with a sample standard deviation of 10.96.

The interval between the issuance of the TA and the RA is the amount of time the crew had to evaluate the situation developing on the traffic advisory display (if installed) and prepare to execute the evasive maneuver. The average time interval was 16.23 seconds with a sample standard deviation of 6.24.

Of the 40 encounters examined, 37 showed an increase in altitude separation at CPA as a result of the TCAS maneuver. The three encounters that showed less altitude separation due to the TCAS maneuvers are encounters 3, 11 and 23. These three cases are similar and are discussed below.

The altitude separation changes resulting from the TCAS maneuver were computed by subtracting the no TCAS maneuver altitude separation at CPA from the results obtained by performing the evasive maneuver. Of the 40 encounters examined, 37 showed a positive change in the altitude separation at CPA as a result of the TCAS maneuver. The three encounters that showed negative values due to the TCAS maneuvers are the same three mentioned above. The TCAS maneuver resulted in an average increase in altitude separation of 577.9 feet.

The slant range changes caused by performing the TCAS maneuver were computed by subtracting the value of the no TCAS maneuver slant range at CPA from the value obtained for the evasive maneuver. As in the other figures, 37 encounters demonstrated a positive change in the slant range at CPA as a result of the TCAS maneuver. The same three scenarios (3, 11, 23) showed negative values. The average increase in the slant range resulting from a

TCAS maneuver was 187.50 feet.

The 40 encounters used in this study are described briefly below. The 12 airline crews who participated in the study flew similar routes and encountered similar air traffic conditions. Eight of the 12 crews (conditions 3 and 4) flew with fully operational TCAS II systems which had both a traffic advisory display and a resolution advisory display. The other four crews (2111, 2221, 2312, and 2412, condition 2) used a minimal system without a traffic display.

Table 1. SUMMARY OF ENCOUNTER ANALYSES

Run No.	TA-CPA	RA-CPA	TA-RA	Vertical distance Maneuver	Vertical distance No maneuver	Altitude Diff TCAS-NoTCAS	Slant Rg Diff TCAS-NoTCAS
1	29	18	11	684.8	295.3	389.5	327.6
2	34	20	14	1005.4	121.5	883.9	648.8
3	25	5	20	1026.9	1051.4	-24.5	-2.2
4	32	18	14	1661.4	652.1	1009.3	118.8
5	19	18	1	425.5	80.7	344.8	89.9
6	42	26	16	581.5	30.6	550.9	31.0
7	27	14	13	1528.0	703.4	824.6	176.2
8	51	36	15	1215.2	382.8	832.4	104.3
9	32	17	15	701.6	18.6	683.0	432.1
10	66	30	36	776.6	93.4	683.2	188.5
11	30	17	13	140.4	645.8	-505.4	-22.0
12	35	14	21	693.4	463.9	229.5	51.5
13	42	27	15	955.1	99.6	855.5	435.4
14	46	28	18	861.4	169.1	692.3	210.9
15	39	26	13	1865.6	257.6	1608.0	316.0
16	52	35	17	1454.2	130.7	1323.5	185.2
17	34	19	15	1860.2	408.4	1451.8	1536.9
18	44	26	18	1105.7	57.6	1048.1	197.2
19	45	29	16	770.5	44.9	725.6	172.6
20	36	21	15	816.8	562.5	254.3	224.0
21	41	26	15	611.7	239.0	372.7	130.3
22	31	17	14	1359.1	1174.8	184.3	61.1
23	33	15	18	264.2	653.7	-389.5	-19.7
24	39	4	35	559.7	522.2	37.5	13.6
25	43	22	21	912.2	127.5	784.7	184.7
26	40	24	16	421.4	374.4	47.0	2.8
27	41	35	6	1648.8	185.4	1463.4	158.5
28	57	41	16	1519.3	297.7	1221.6	188.0
29	86	70	16	1004.3	982.4	21.9	13.6
30	34	18	16	453.8	105.5	348.3	68.5
31	40	24	16	545.8	44.5	501.3	38.0
32	42	26	16	653.1	188.7	464.4	159.3
33	40	24	16	1602.9	47.2	1555.7	143.4
34	43	16	27	772.7	614.7	158.0	51.4
35	25	9	16	1181.5	914.4	267.1	73.2
36	30	15	15	1195.3	699.7	495.6	88.2
37	20	16	4	1053.1	652.7	400.4	253.4
38	44	24	20	822.4	510.8	311.6	284.2
39	41	26	15	771.6	235.3	536.3	55.6
40	40	25	15	532.5	60.9	471.6	129.1

Description of Encounters

SCENARIO #1 - CREW #2111:

CONDITIONS: time = 00:40:12; altitude = 1996 feet (ft); descending; descent rate = -4.33 feet per second (FPS) or -259 feet per minute (FPM).

NARRATIVE: The crew received a "descend" command requiring an increase in descent rate. The maneuver resulted in an increase in altitude and slant range (389 FT, 327 FT) at CPA compared to continuing to descend at -259 FPM.

SCENARIO #2 - CREW #2111:

CONDITIONS: time = 10:20:43; altitude = 10145 FT; level flight.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (883 FT, 648 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #3 - CREW #2221:

CONDITIONS: time = 03:52:13; altitude = 33075 FT; level flight.

NARRATIVE: The crew received a "descend to cross" command to avoid an intruder aircraft (call sign "FOG 26") which was climbing underneath the TCAS aircraft. The CPA occurred five seconds after the command was given. The maneuver resulted in a decrease in altitude separation and slant range (-24.5FT, -2.2 FT) at CPA compared to continuing level at the assigned altitude. This is the first of three similar incidents involving FOG 26 that is being studied to determine the cause of these undesirable results. The slant range at CPA in this case was 11458 FT (1.9 NM).

SCENARIO #4 - CREW #2221:

CONDITIONS: time = 04:14;12; altitude = 12093 FT; descending; descent rate = -32.53 FPS or -1951.8 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command which required a level off. The maneuver resulted in an increase in altitude separation and slant range (1009 FT, 118 FT) at CPA compared to continuing the descent at -1951FPM.

SCENARIO #5 - CREW #2221:

CONDITIONS: time = 07:19:46; altitude = 11070 FT; leveling at 11000 FT.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (344 FT, 89 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #6 - CREW #2221:

CONDITIONS: time = 09:51:35; altitude = 5228 FT; descending; descent rate = -10.15 FPS or -609 FPM; clearance = "descend and maintain 5000 FT".

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (550 FT, 31 FT) at CPA compared to continuing the descent at -609 FPM to a level off altitude of 5000 FT.

SCENARIO #7 - CREW #2312:

CONDITIONS: time = 08:02:14; altitude = 32990 FT; level flight.

NARRATIVE: The crew received a "climb" command to avoid a conflicting aircraft (FOG 26) which was climbing underneath the TCAS aircraft. Unlike scenario 3, the climb maneuver resulted in an increase in altitude separation and slant range (824 FT, 176 FT) at CPA compared to continuing level flight at the assigned altitude. This scenario is similar to scenario 3 but had a 14 second time interval between RA and CPA and a slant range of 5309 FT (.87 NM) at CPA. In this case, the TCAS maneuver improved the separation between the TCAS aircraft and FOG 26.

SCENARIO #8 - CREW #2312:

CONDITIONS: time = 08:22:27; altitude = 12058 FT; descending; descent rate = -48.86 FPS or -2931 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command followed by a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (832 FT, 104 FT) at CPA compared to continuing to descend at -2931 FPM.

SCENARIO #9 - CREW #2312:

CONDITIONS: time = 10:02:09; altitude = 10095 FT; level flight.

NARRATIVE: The crew received a "climb to cross" command followed by a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (683 FT, 432 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #10 - CREW #2312:

CONDITIONS: time = 10:06:52; altitude = 7639 FT; descending; descent

C-2

rate = -28.8 FPS or -1728 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command calling for no descent greater than 500 FPM. The maneuver resulted in an increase in altitude separation and slant range (683 FT, 188 FT) at CPA compared to continuing the descent at -1728 FPM.

SCENARIO #11 - CREW #2422:

CONDITIONS: time = 04:28:33; altitude = 33004 FT; level flight.

NARRATIVE: The crew received a "descend to cross" command to avoid an intruder aircraft (FOG 26) which was climbing below the TCAS aircraft. CPA occurred 17 seconds after the command was given. The maneuver resulted in a decrease in altitude separation and slant range (-505 FT, -22 FT) at CPA compared to continuing level at the assigned altitude. This is the second of three similar incidents involving FOG 26 that is under investigation. The slant range at CPA in this case was 9009 FT (1.5 NM).

SCENARIO #12 - CREW #2422:

CONDITIONS: time = 07:28:20; altitude = 2260 FT; descending; descent rate = -19.53 FPS or -1171 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command calling for no descent greater than 500 FPM. The maneuver resulted in an increase in altitude separation and slant range (229 FT, 51 FT) at CPA compared to continuing the descent at -1171 FPM.

SCENARIO #13 - CREW #2422:

CONDITIONS: time = 10:28:03; altitude = 5059 FT; descending; descent rate = -3.02 FPS or -990 FPM; clearance = "descend and maintain 5000 FT".

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (855 FT, 435 FT) at CPA compared to continuing the descent to 5000 FT.

SCENARIO #14 - CREW #3111:

CONDITIONS: time = 03:36:15; altitude = 3760 FT; descending; descent rate = -32.62 FPS or -1957 FPM.

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (692 FT, 210 FT) at CPA compared to continuing the descent at -1957 FPM.

SCENARIO #15 - CREW #3111:

CONDITIONS: time = 07:14:48; altitude = 32991 FT; level flight.

NARRATIVE: The crew received a "descend to cross" command to avoid an intruder aircraft (FOG 26) which was climbing underneath the TCAS aircraft. CPA occurred 26 seconds after the command was given. Unlike encounters 3 and 11, this maneuver resulted in an increase in altitude separation and slant range (1608 FT, 316 FT) at CPA compared to maintaining level flight at the assigned altitude. The slant range at CPA in this case was 5559 FT (0.9 NM) which is much smaller than the slant ranges in the two encounters mentioned above. In this case, a "descend to cross" command improved the situation.

SCENARIO #16 - CREW #3111:

CONDITIONS: time = 07:37:15; altitude = 11647 FT; descending; descent rate = -26.54 FPS or -1592 FPM.

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (1323 FT, 185 FT) at CPA compared to continuing the descent at -1592 FPM.

SCENARIO #17 - CREW #3111:

CONDITIONS: time = 09:28:25; altitude = 10016 FT; level flight.

NARRATIVE: The crew received a "climb to cross" command. The maneuver resulted in an increase in altitude separation and slant range (1451 FT, 1536 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #18 - CREW #3221:

CONDITIONS: time = 06:53:04; altitude = 3937 FT; descending; descent rate = -28.49 FPS or -1709 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command followed by a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (1048 FT, 197 FT) at CPA compared to continuing the descent at -1709 FPM.

SCENARIO #19 - CREW #3221:

CONDITIONS: time = 09:54:04; altitude = 5175 FT; climbing; climb rate = +4.15 FPS or +249 FPM; clearance = "descend and maintain 5000 FT".

NARRATIVE: The crew used the information from the traffic advisory display to anticipate the collision situation developing and started to climb shortly before they received a "climb" command from the resolution advisory display. The maneuver resulted in an increase in altitude separation and slant range (725 FT, 172 FT) at CPA compared to continuing the descent to their assigned level-off altitude of 5000 FT.

SCENARIO #20 - CREW #3312:

CONDITIONS: time = 01:21:09; altitude = 1903 FT; descending; descent rate = -13.82 FPS or -829 FPM.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (254 FT, 224 FT) at CPA compared to continuing the descent at -829 FPM.

SCENARIO #21 - CREW #3312:

CONDITIONS: time = 02:33:07; altitude = 5189 FT; descending; descent rate = -19.59 FPS or -1175 FPM.

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (372 FT, 130 FT) at CPA compared to continuing the descent at -1175 FPM.

SCENARIO #22 - CREW #3312:

CONDITIONS: time = 07:43:86; altitude = 12156 FT; descending; descent rate = -26.06 FPS or -1563 FPM.

NARRATIVE: This is another case where the crew used the information from the traffic advisory display to anticipate the collision situation developing and started to level off before an "adjust vertical speed" command was received from the resolution advisory display. The maneuver resulted in an increase in altitude separation and slant range (184 FT, 61 FT) at CPA compared to continuing to descend at their original descent rate, which was greater than 2000 FPM prior to the crew-initiated level off.

SCENARIO #23 - CREW #3422:

CONDITIONS: time = 03:54:10; altitude = 32982 FT; level flight.

NARRATIVE: The crew received a "descend to cross" command to avoid an intruder aircraft (FOG 26) which was climbing underneath the TCAS aircraft. CPA occurred 15 seconds after the command was given. The maneuver resulted in a decrease in altitude separation and slant range (-389 FT, -19 FT) at CPA compared to continuing level at the assigned altitude. This is the third of three similar incidents involving FOG 26 that is being studied. The slant range at CPA in this case was 9075 FT (1.5 NM).

SCENARIO #24 - CREW #3422:

CONDITIONS: time = 04:20:34; altitude = 6983 FT; level flight.

NARRATIVE: The crew was leveling at 7000 FT when they received a "descend" command to avoid conflicting traffic at 7500 FT. CPA occurred four seconds after the resolution alert was issued. The maneuver resulted in a small increase in altitude separation and slant range (37 FT, 13 FT) at CPA compared to remaining level. It appears that the system did not consider the conflicting aircraft a threat until the TCAS crew arrested their descent and leveled off. The actual altitude separation between aircraft at CPA was 560 FT with a slant range of 1496 FT.

SCENARIO #25 - CREW #3422:

CONDITIONS: time = 09:17:36; altitude = 5370 FT; climbing; climb rate = +12.78 FPS or +766 FPM; clearance = "descend and maintain 5000 FT".

NARRATIVE: This case is similar to scenario 19. The crew used the information from the traffic advisory display to anticipate the collision situation developing and started to climb shortly before a "climb" command from the resolution advisory display was received. The maneuver resulted in an increase in altitude separation and slant range (784 FT, 184FT) at CPA compared to continuing the descent to their assigned level-off altitude of 5000 FT.

SCENARIO #26 - CREW #4111:

CONDITIONS: time = 07:13:19; altitude = 32994 FT; level flight.

NARRATIVE: This case is similar to scenario 15. The crew received a "descend to cross" command to avoid an intruder aircraft (FOG 26) which was climbing below the TCAS aircraft. CPA occurred 24 seconds after the command was given. Unlike encounters 3, 11, and 23, the maneuver resulted in a small increase in altitude separation and slant range (47 FT, 2.8 FT) at CPA compared to maintaining level flight at the assigned altitude. The slant range at CPA in this case was 6629 FT (1.1 NM) which is smaller than the slant ranges in the three encounters mentioned above.

SCENARIO #27 - CREW #4111:

CONDITIONS: time = 07:34:16; altitude = 12324 FT; descending; descent rate = -55.72 FPS or -3343 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command which required no descent greater than 1000 FPM. The maneuver resulted in an increase in altitude separation and slant range (1463 FT, 158 FT) at CPA compared to continuing the descent at -3343 FPM.

SCENARIO #28 - CREW #4221:

CONDITIONS: time = 04:10:59; altitude = 32995 FT; level flight.

NARRATIVE: This case is similar to encounters 15 and 26. The crew received a "descend to cross" command to avoid an intruder aircraft (FOG 26) which was climbing underneath the TCAS aircraft. CPA occurred 41 seconds after the command was given. The maneuver resulted in an increase in altitude separation and slant range (1221 FT, 188 FT) at CPA compared to maintaining level flight at the assigned altitude. The slant range at CPA in this case was 5998 FT (.99 NM).

SCENARIO #29 - CREW #4221:

CONDITIONS: time = 06:31:28; altitude = 3018 FT; descending; descent rate = -13.89 FPS or -833 FPM.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (21 FT, 13 FT) at CPA compared to continuing the descent at -833 FPM.

SCENARIO #30 - CREW #4221:

CONDITIONS: time = 01:35:13; altitude = 2064 FT; leveling at 2000 FT.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (348 FT, 68 FT) at CPA compared to maintaining level flight at the assigned altitude of 2000 FT.

SCENARIO #31 - CREW #4221:

CONDITIONS: time = 02:46:49; altitude = 5127 FT; descending; descent rate = -12.88 FPS or -772 FPM; clearance = "descend and maintain 5000 FT".

NARRATIVE: The crew received a "descend to cross" command, the maneuver resulted in an increase in altitude separation and slant range (501 FT, 38 FT) at CPA compared to continuing the descent at -772 FPM until level at 5000 FT.

SCENARIO #32 - CREW #4312:

CONDITIONS: time = 02:12:24; altitude = 5080 FT; level flight.

NARRATIVE: The crew received a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (464 FT, 159 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #33 - CREW #4312:

CONDITIONS: time = 03:47:28; altitude = 3954 FT; descending; descent rate = -21.25 FPS or -1275 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command followed by a "climb" command. The maneuver resulted in an increase in altitude separation and slant range (1555 FT, 143 FT) at CPA compared to continuing the descent at -1245 FPM.

SCENARIO #34 - CREW #4312:

CONDITIONS: time = 03:49:39; altitude = 2163 FT; descending; descent rate = -12.67 FPS or -760 FPM; clearance = "descend and maintain 2000 FT".

NARRATIVE: The crew received an "adjust vertical speed" requiring no descent greater than 0 FPM. The maneuver resulted in an increase in altitude separation and slant range (158 FT, 51 FT) at CPA compared to continuing the descent at -760 FPM until level at 2000 FT.

SCENARIO #35 - CREW #4312:

CONDITIONS: time = 07:07:53; altitude = 33008 FT; level flight.

NARRATIVE: The crew received a "climb" command to avoid an intruder aircraft (FOG 26) which was climbing below the TCAS aircraft. CPA occurred nine seconds after the command was given. The maneuver resulted in an increase in altitude separation and slant range (267 FT, 73 FT) at CPA compared to maintaining level flight at the assigned altitude. The slant range at CPA in this case was 3858 FT (.60 NM).

SCENARIO #36 - CREW #4422:

CONDITIONS: time = 04:23:00; altitude = 33086 FT; level flight.

NARRATIVE: This scenario is similar to scenario 35. The crew received a "climb" command to avoid an intruder aircraft (FOG 26) which was climbing below the TCAS aircraft. CPA occurred 15 seconds after the command was given. The maneuver resulted in an increase in altitude separation and slant range (495 FT, 88 FT) at CPA compared to maintaining level flight at the assigned altitude. The slant range at CPA was 5266 FT (.86 NM).

SCENARIO #37 - CREW #4422:

CONDITIONS: time = 04:43:56; altitude = 12035 FT; descending; descent rate = -37.95 FPS or -2277 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command requiring no descent greater than 2000 FPM. The crew reacted by significantly reducing their descent rate. The maneuver resulted in an increase in altitude separation and slant range (400 FT, 253 FT) at CPA compared to continuing the descent at -2277 FPM.

SCENARIO #38 - CREW #4422:

CONDITIONS: time = 04:49:10; altitude = 6998 FT; level flight.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (311 FT, 284 FT) at CPA compared to maintaining level flight at the assigned altitude.

SCENARIO #39 - CREW #4422:

CONDITIONS: time = 07:10:44; altitude = 3905 FT; descending; descent rate = -18.21 FPS or -1092 FPM.

NARRATIVE: The crew received an "adjust vertical speed" command which required no descent greater than 500 FPM. The crew significantly reduced their descent rate and even climbed slightly. The maneuver resulted in an increase in altitude separation and slant range (536 FT, 55 FT) at CPA compared to continuing the descent at -1092 FPM.

SCENARIO #40 - CREW #4422:

CONDITIONS: time = 10:26:45; altitude = 4947 FT; level flight.

NARRATIVE: The crew received a "descend" command. The maneuver resulted in an increase in altitude separation and slant range (471 FT, 129 FT) at CPA compared to maintaining level flight at the assigned altitude.

CONCLUSIONS

The TCAS II system maneuver commands resulted in increased vertical separations and slant range distances between TCAS equipped aircraft and conflicting aircraft for 37 of the 40 encounters studied. The three encounters (3, 11, 23) which showed a decrease in vertical separation and slant range (miss distance) at the closest point of approach (CPA) are unexpected results; some characteristics of these encounters are noted here.

All three had the following common characteristics: the conflicting aircraft was climbing rapidly underneath the TCAS aircraft when the resolution alert (RA) was issued; the TCAS aircraft was straight and level at approximately 33000 feet; and the resolution alert called for a "descend to cross" maneuver. The time interval between the RA and CPA on all three encounters (5 secs, 17 secs, 15 secs) was shorter than the average time for the 40 cases (23 secs). The slant ranges at CPA for these three cases were in excess of 9000 feet or 1.48 nautical miles (11458 FT, 9009 FT, 9075 FT). There were six other encounters involving the same intruder aircraft in this study (7, 15, 26, 28, 35, 36) which all showed increases in vertical separation and slant range at CPA as a result of performing the recommended evasive maneuver. Three of these six (7, 35, 36) received "climb" commands from the TCAS system. The other three encounters (15, 26, 28) received "descend to cross" commands (similar to 3, 11, and 23); but, in these cases, the times from RA to CPA (26 secs, 24 secs, 41 secs) were longer than the average. Also, these three (15, 26, 28) showed much shorter slant ranges at CPA (5559 FT, 6629 FT, 5998 FT) than the three encounters with decreased separation (3, 11, 23).

Further analysis of the three anomalous encounters indicated that TCAS inaccurately predicted the time to CPA because of a large lateral miss distance. The TCAS II logic does not consider bearing information; the system was therefore unaware that the lateral miss distance would be so large. In none of these three encounters was closest separation less than 9000 ft horizontally.

The results of this study also demonstrate that three encounters (1, 2, 9) would have resulted in dangerous situations if the recommended TCAS maneuver had not been performed. Without a TCAS maneuver, these three conflicts would have resulted in slant ranges (miss distances) of less than 500 feet with altitude separations between the two aircraft of less than 300 feet. It should be noted that no dangerous situations developed when the crews used the TCAS system.

An analysis of the flight station video recordings indicates that the "adjust vertical speed" voice command was confusing for some of the pilots. The terminology of this command is ambiguous in that it does not specify an increase or a decrease in climb or descent rate. Several Captains told the First Officer at the controls to "level off" when the resolution advisory display required only a decrease in descent rate. An improvement in the wording of this command or a better presentation on the RA display may help to reduce the confusion that was noted in this study.

Overall, the TCAS II system should result in a significant enhancement to the "see and avoid" procedures in the cockpit and dramatically improve the safety of airline travel.

Appendix R: USE OF THE TCAS TRAFFIC ADVISORY DISPLAY FOR EVASIVE MANEUVERING

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INTRODUCTION

The TCAS II traffic advisory display is designed to be used by pilots to aid them in establishing visual contact with conflicting traffic. It may also be used to observe the flight paths of nearby traffic and monitor the relative altitude differences between the TCAS aircraft and other aircraft in the vicinity. This allows the pilots to see dangerous situations developing and prepare for possible evasive maneuvering. Eight airline flight crews participated in the NASA-Ames TCAS II study using systems which utilized this display as well as the IVSI display. They were thoroughly briefed that the traffic advisory display was for traffic information only and was not to be used for evasive maneuvering. The IVSI display was to be used for evasive maneuvers in the vertical plane following a resolution advisory. In general, the pilots adhered to the guidelines that they were given. There were fourteen incidents where the pilots used their own experience and judgement to maneuver the aircraft based on the traffic advisory display information. Each of these incidents will be examined in this report.

PROCEDURES

The use of the information obtained from the traffic advisory display for maneuvering was investigated using information from three different sources.

(1) Computer printouts of the TCAS-equipped aircraft's data for all occurrences of a heading change or bank angle greater than 10 degrees were examined for the time period from two minutes before a traffic alert through the end of the alert. Similar printouts for resolution alerts were investigated using the same parameters. All incidents of altitude deviations of 100 feet or greater, or vertical velocity changes of greater than 500 feet per minute, were also examined for the TCAS aircraft before and during the traffic and resolution alert time periods.

(2) Two observers monitored the flight crew's actions during the simulator testing. Both individuals filled out forms which contained the conditions for each alert as well as comments from their personal observations. These reports were a valuable source of data. Another source of information was the corrective RA analysis forms completed during post-flight data reduction (Appendix M).

(3) Cockpit video tapes were used to observe the flight crew's responses to the traffic advisory information and were used to confirm the incidents of maneuvering based on this information.

All maneuvers which were based on visual sightings were not counted as adjustments or improper use of the system, unless the evasive maneuvers used traffic advisory information after visual contact was lost. Maneuvers based on ATC clearances or navigation maneuvers also were not counted as adjustments.

RESULTS

Fourteen incidents of maneuvering based on information obtained from the traffic advisory display are described. Each crew's incidents are grouped together to show trends.

CREW #3111: No incidents.

CREW #3221: 2 altitude adjustments and 2 turns.

(1) CONDITIONS: time = 07:51:00; visual contact, then lost visual contact during maneuvering; twilight; visual meteorological conditions; descending.

NARRATIVE: Crew adjusted their descent rate during the approach in response to a traffic advisory showing traffic beneath them. After clearing the traffic they continued their approach.

(2) CONDITIONS: time = 09:06:49; no visual contact; twilight; visual meteorological conditions; climbing.

NARRATIVE: Crew turned to the right to avoid a mode A aircraft after takeoff during the climb. Aircraft that are mode A transponder equipped do not have altitude reporting capability, and thus show up on the traffic advisory display with no relative altitude information. Additionally, no resolution alerts or recommended evasive maneuvers can be issued for these types of aircraft. The crew discussed the incident and decided that the turn was needed to ensure separation since they did not know what altitude the other aircraft was flying at.

(3) CONDITIONS: time = 09:53:48; no visual contact; twilight; visual meteorological conditions; descending.

NARRATIVE: Crew was descending to level at 5000 feet. After evaluating the information on the traffic display, they leveled off slightly above their assigned level off altitude and started a slight climb. A resolution advisory calling for a climb was issued a few seconds after they started to climb. After clearing the traffic, they descended to their assigned altitude.

(4) CONDITIONS: time = 09:58:35; no visual contact; twilight; visual meteorological conditions; descending.

NARRATIVE: Crew turned right to clear mode A traffic on a localizer approach using information obtained from the traffic advisory display. After clearing the traffic they completed the approach.

CREW #3312: 1 altitude adjustment.

(1) CONDITIONS: time = 07:47:33; no visual contact; night; visual meteorological conditions; descending.

NARRATIVE: During a descent, the crew responded to the information on the traffic advisory display which showed an aircraft 1000 feet below them. They decided to level the aircraft instead of continuing their descent. This resulted in the crew having to notify ATC that they would not be able to meet a crossing altitude clearance. After clearing the traffic they continued their descent.

CREW #3422: 1 turn and 1 altitude adjustment.

(1) CONDITIONS: time = 03:53:52; visual contact then lost visual contact; night; visual meteorological conditions; level flight.

NARRATIVE: Crew had visual contact on a conflicting aircraft but lost sight of it. The traffic advisory display showed the traffic at 12:30 and climbing below them. A resolution alert advised the crew to "descend to cross" in order to cross under the conflicting aircraft. The pilot in command decided to descend as instructed and turn left slightly to increase the separation distance. Visual contact was regained after the evasive maneuver.

(2) CONDITIONS: time = 09:17:15; no visual contact; night; visual meteorological conditions; descending.

NARRATIVE: The crew was descending for an approach with multiple aircraft in the area when they received a traffic advisory on an aircraft climbing below their aircraft. The pilot in command anticipated the possibility of a collision and advanced the power on the engines to level off. As he responded the TCAS system issued a resolution alert and gave the crew a "climb" command. He followed the instructions, remained clear of the other aircraft and finally resumed his approach.

CREW #4111: 1 altitude adjustment.

(1) CONDITIONS: time = 02:27:24; visual contact after the maneuver; twilight; visual meteorological conditions; descending.

NARRATIVE: The crew was descending for an approach when they received a traffic advisory and noticed that they were descending on top of another aircraft. Using this information, they stopped their descent and attempted to notify ATC of their situation. Visual contact was finally established on the other aircraft and they maintained their altitude until the other aircraft passed beneath them.

CREW #4221: 3 altitude adjustments.

(1) CONDITIONS: time = 04:35:50; no visual contact, twilight; visual

meteorological conditions; descending.

NARRATIVE: The crew was descending for an approach when the traffic advisory displayed a conflicting aircraft at 1200. The crew evaluated the range and altitude several times before deciding to level off while the aircraft was still 4 miles away. They continued to evaluate the information that was presented and decided that the aircraft was going the same way they were and that they could "sneak under him". They continued their descent behind the other aircraft and completed their approach. The crew never received a resolution alert due to their maneuvering on the traffic advisory display information.

(2) CONDITIONS: time = 06:30:00; no visual contact; twilight; visual meteorological conditions; level flight.

NARRATIVE: ATC cleared the crew to descend. The crew hesitated due to traffic on the traffic advisory display and asked ATC for a clearance to remain level. ATC reiterated that they were cleared to descend and the crew complied by "descending quickly" to stay clear of traffic. During the descent they received a resolution alert calling for a descent. This crew monitored the traffic advisory display during maneuvering and wanted to continue descending after clearing traffic. They decided not to after a short discussion of their ATC clearance and terrain clearance considerations. They maintained their assigned level off altitude until they were clear of the traffic.

(3) CONDITIONS: time = 06:33:40; visual contact then lost visual contact; twilight; visual meteorological conditions; descending.

NARRATIVE: On a localizer approach, the crew had the traffic visually then lost it. They were concerned with the other aircraft's position and used the traffic advisory display's information to stay "a little higher" than the other aircraft until they were clear. They adjusted their descent rate to maintain vertical separation. One pilot from this crew stated "we are really trusting an instrument a lot".

CREW #4312: 1 turn.

(1) CONDITIONS: time = 01:25:24; no visual contact; night; visual meteorological conditions; climbing.

NARRATIVE: The crew was climbing after takeoff. They responded to a traffic advisory on the display by delaying a required turn until they were clear of the traffic. The pilot did not begin the turn until the other pilot informed him that they were past the traffic on the display.

CREW #4422: 1 turn and 1 altitude adjustment.

(1) CONDITIONS: time = 03:20:05; no visual contact; night; instrument meteorological conditions; descending.

NARRATIVE: While descending in the clouds, the crew responded to a traffic advisory by turning "hard left" to avoid a mode A aircraft. The pilot in command justified the turn by concluding that since TCAS resolution alerts and evasive maneuvers are not available for mode A traffic he had to maneuver to ensure safe separation. The other pilot responded that the other aircraft was probably in VMC conditions below the clouds. After clearing the traffic the crew returned to course.

(2) CONDITIONS: time = 10:26:30; visual contact after the maneuver; night; visual meteorological conditions; descending.

NARRATIVE: The crew was cleared to descend to an assigned altitude. Approaching the assigned altitude, the crew received a traffic alert showing an aircraft 200 feet below them. They decided to level off and advanced power on the engines. During the level off maneuver, a resolution alert occurred calling for a descent. The crew complied with the command and descended. During the descent they obtained visual contact as they passed under the other aircraft.

CONCLUSIONS

An analysis of the fourteen incidents shows a few patterns. Altitude adjustments accounted for 64% of the total adjustments (9 out of 14). The majority of the adjustments occurred during descents (10 out of 14). Three of the turn adjustments involved maneuvers to avoid a mode A transponder equipped aircraft. The most common scenario involved the TCAS aircraft descending on top of another aircraft. These situations gave the pilots enough warning so that they could observe the dangerous situation developing on the traffic advisory display and take corrective action. The corrective action usually resulted in a decrease in the rate of descent or a level off above the assigned altitude for a short period of time. All of the fourteen adjustments caused small deviations from ATC clearances for short time periods. Each crew attempted to notify ATC of the deviations that were required as soon as workload permitted.

Pilot training programs will need to be implemented to standardize the use of the TCAS II system. The responsibility for safety of flight for an aircraft rests with the pilot in command. The training must emphasize this responsibility and allow him (or her) to use all the information available to maintain a safe distance from other aircraft. Turns away from mode A transponder equipped aircraft should be discouraged. The inaccuracy of the bearing and altitude information from the traffic advisory display must be emphasized. The possibility of degrading the performance of the TCAS computer's evasive maneuver commands by maneuvering on the traffic display should be discussed. Pilots must learn to use the system the way the designers intended it to be used, but they also must remember to use their training and experience to evaluate situations and take appropriate action to ensure safety of flight.

APPENDIX S: POST-FLIGHT QUESTIONNAIRE RESULTS

Note: The average ratings provided by flight crews are shown just above the scale accompanying each question; where responses differed significantly across experimental conditions, C2, C3 or C4 identifies the average of the responses for each experimental group of four crews (12 crew members). Numbers below multiple-choice questions identify the response frequencies.

Post-Flight Questionnaire for the NASA/FAA TCAS Human Factors Study

Now that you have this simulation we would like to get your evaluation of the system and its use. Remember this research will provide input to the ultimate design and implementation of the TCAS which will eventually be in your airplane. It is very important that you carefully answer each question. Generally it is best to record the response that first comes to mind.

This questionnaire is meant to be a starting point for your evaluation, don't limit your responses to these questions. Use the reverse sides of the pages to expand and extrapolate from these issues.

Please mark the point on the scale best representing your evaluation of the following items.

Crew Member: Capt F/O S/O

In comparing this simulation to typical line flights:

1. The cockpit procedures and duties in this simulation were:

very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic — $\bar{x}=8.3$

2. The air traffic control services in this simulation were:

very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic — $\bar{x}=8.5$

3. The aircraft response to manual control input was:

very unrealistic |___|___|___|___|___|___|___|___|___|___| very realistic — $\bar{x}=6.7$

4. The differences between the aircraft you fly and this simulator were:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting — $\bar{x}=6.3$

5. How often were you aware of the location of known traffic?

never |___|___|___|___|___|___|___|___|___|___| always — $\bar{x}=7.3$

6. The information from ATC traffic advisories and seeing the aircraft out of the window was:

often conflicting |___|___|___|___|___|___|___|___|___|___| never conflicting — $\bar{x}=6.4$

7. Did you ever take evasive action to avoid another aircraft? yes 43 no 2

8. What type of evasive maneuver do you prefer?

no preference	climbs/descents	turns
13	11	18

9. What are your current procedures for ATC traffic advisories and see-and-avoid? ____

____

____

10. What ways could the air traffic controller better help you to avoid near mid air collisions? ____

____

____

11. Based upon your actual flight experience does a collision threat exist?

strongly disagree |___|___|___|___|___|___|___|___|___|___| strongly agree ($\bar{x}=7.4$)

Questions Concerning the use of the TCAS:

12. For the purpose of operating TCAS, your understanding of the operation and limitations of TCAS is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete ($\bar{x}=7.0$)

13. For the purpose of operating TCAS, your understanding of the TCAS traffic advisory is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete ($\bar{x}=7.1$)

14. For the purpose of operating TCAS, your understanding of the TCAS maneuver advisory is:

very limited |___|___|___|___|___|___|___|___|___|___| very complete ($\bar{x}=7.0$)

15. The training you received for TCAS use was:

very inadequate |___|___|___|___|___|___|___|___|___|___| very adequate ($\bar{x}=8.3$)

16. The operational procedures for TCAS use were:

very inappropriate |___|___|___|___|___|___|___|___|___|___| very appropriate ($\bar{x}=7.5$)

17. The addition of TCAS to the other flight duties was:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting (C4=6.2 C2=7.9 C3=8.0)

18. After several months of use in line service TCAS would be:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting ($\bar{x}=7.1$)

19. For reducing the risk of mid-air collisions, TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

x̄=8.0

20. For aiding visual contact with the traffic, TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

C2=4.3 C3=8.3 C4=9.3

21. Would TCAS affect the time you normally spend scanning for traffic?

increase scan time |___|___|___|___|___|___|___|___|___|___|___| decrease scan time

x̄=4.6

22. The information from ATC traffic advisories and the TCAS was:

often conflicting |___|___|___|___|___|___|___|___|___|___|___| never conflicting

x̄=6.8

23. Would TCAS increase or decrease contact with ATC?

greatly increase |___|___|___|___|___|___|___|___|___|___|___| greatly decrease

x̄=5.0

24. In rare instances TCAS is unable to recommend a resolution ("Unable to Command"), given this limitation, do you feel TCAS is an acceptable system for reducing the risk of mid-air collisions?

very unacceptable |___|___|___|___|___|___|___|___|___|___|___| very acceptable

x̄=7.7

25. What did you do when this occured? ______________________________

____

26. Was the aural alert and caution/warning light effective in getting your attention?

very ineffective |___|___|___|___|___|___|___|___|___|___|___| very effective

C4=7.2 C2=8.5 C3=8.2

27. Was the aural alert and caution/warning light distracting in their function of getting your attention?

very distracting |___|___|___|___|___|___|___|___|___|___|___| not at all distracting

C4=5.6 C2=7.8 C3=8.5

28. In preparing for evasive maneuvers, the TCAS traffic advisory was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

x̄=7.7

29. In executing TCAS evasive maneuvers, the voice command was:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful

x̄=7.6

30. For communicating the recommended evasive action or restriction to vertical rate, the lights on the IVSI were:

difficult to interpret |___|___|___|___|___|___|___|___|___|___|___| easy to interpret

x̄=8.5

31. The average time it took you to initiate the evasive maneuver, after the TCAS warning, was 3.1 seconds.

32. The evasive maneuvers as prescribed by TCAS were:

very unacceptable |___|___|___|___|___|___|___|___|___|___|___| very acceptable ($\bar{x}$=7.7)

33. The IVSI indications of unsafe vertical rates (when evasive action was not required) were:

not at all useful |___|___|___|___|___|___|___|___|___|___|___| very useful ($\bar{x}$=7.4)

34. Did you ever take evasive action without being told to by TCAS? yes 25 no 9

if so, did you do so based on visual contact with the traffic? yes 22 no 2

35. Did you ever maneuver differently than TCAS instructed? yes 6 no 28

36. If so, please explain ______________________________

____

37. Were you reluctant to perform a TCAS maneuver that required you to cross through another aircraft's altitude?

very reluctant |___|___|___|___|___|___|___|___|___|___|___| not at all reluctant (C4=4.5 C2=5.4 C3=6.9)

38. Were you reluctant to perform a TCAS maneuver in conflict with your ATC clearance?

very reluctant |___|___|___|___|___|___|___|___|___|___|___| not at all reluctant ($\bar{x}$=6.5)

39. Would you be reluctant to maneuver in conflict with your ATC clearance if the rules were changed so that TCAS evasive action was endorsed?

very reluctant |___|___|___|___|___|___|___|___|___|___|___| not at all reluctant ($\bar{x}$=8.6)

40. Were you reluctant to perform a TCAS maneuver in IMC?

very reluctant |___|___|___|___|___|___|___|___|___|___|___| not at all reluctant (C4=4.8; C2=7.4; C3=7.5)

41. Operation of TCAS in IMC and VMC was:

very different |___|___|___|___|___|___|___|___|___|___|___| not at all different ($\bar{x}$=7.2)

Please explain: ______________________________

42. Would you be satisfied with this TCAS system as a safety enhancement to the airplane you fly?

greatly dissatisfied |___|___|___|___|___|___|___|___|___|___|___| greatly satisfied ($\bar{x}$=7.6)

43. Were there instances where the TCAS did not perform as you expected it to?

Please explain: ______________________________

____

44. Were inappropriate maneuvers prescribed? Please explain:

____

____

45. How often did you contact ATC regarding traffic conflicts identified by TCAS?

$\bar{x}$=2.5

always |___|___|___|___|___|___|___|___|___|___| never

46. What changes would be appropriate in pilot and controller operating procedures with the implementation of TCAS? ____________________

____

____

47. What is the feature you liked most about TCAS? ____________________

____

____

____

48. What is the feature you liked least about TCAS? ____________________

____

____

____

Questions Concerning the Information on the Traffic Advisory Display:

49. In general, the traffic information was:

$\bar{x}$=9.0

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

50. The information on the display was:

$\bar{x}$=7.8

not ay all legible |___|___|___|___|___|___|___|___|___|___| very legible

51. Interpreting the information on the display was:

$\bar{x}$=8.6

difficult to interpret |___|___|___|___|___|___|___|___|___|___| easy to interpret

52. Were the different colors and symbol shapes of targets helpful in recognizing threats?

C4=8.3

not at all helpful |___|___|___|___|___|___|___|___|___|___| very helpful

52a. Were the different colors of targets helpful in recognizing threats?
not at all helpful |___|___|___|___|___|___|___|___|___|___| very helpful
C3=7.2

53. The number of targets on the display was:
too few |___|___|___|___|___|___|___|___|___|___| too many
x̄=4.2

54. The maximum number of targets seen on the display at one time was? 3.5

55. Additional filtering of targets (either manual or automatic) would be:
very undesirable |___|___|___|___|___|___|___|___|___|___| very desirable
x̄=5.3

56. The 3 and 5 mile fixed range rings on the display were:
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C4=8.0

56a. The 2 mile fixed range ring on the display was:
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C3=8.9

57. What value of fixed range rings would you substitute or add? 2.1

58. The horizontal/vertical range you generally used for departure and climb was ______/______, for cruise ______/______, for descent ______/______, for approach ______/______.

59. Being able to vary the horizontal range for targets to be displayed was:
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C4=6.8

In what way?______________________________

59a.Being able to vary the horzontal range for targets to be displayed would be
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C3=6.2

61. Being able to vary the vertical range for targets to be displayed was:
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C4=7.4

In what way? ______________________________

61a. Being able to vary the vertical range for targets to be displayed would be:
not at all useful |___|___|___|___|___|___|___|___|___|___| very useful
C3=6.5

63. Would you prefer a system that automatically switched horizontal and vertical ranges? yes no
4 19

64. The location of the display was:
very poor |___|___|___|___|___|___|___|___|___|___| very good
C4=5.2 C3=7.6

64a. Pushing the traffic switch to display the 8 most important targets being tracked by TCAS was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

C3=6.2

64b. Could the triangle symbol at the other aircraft's location be omitted and the data block adequately represent its location? yes 2 no 9 Cond 3 only

65. How often did you use the arrows to determine if traffic was climbing or descending?

never |___|___|___|___|___|___|___|___|___|___| often

$\bar{x}$=8.4

66. Did the traffic display ever cause you to expect a climb when TCAS told you to descend, or vice versa? yes 6 no 16

67. Please explain: ______________________________

____

68. In executing evasive maneuvers, the symbol for the type of maneuver in the upper left corner was:

not at all useful |___|___|___|___|___|___|___|___|___|___| very useful

C4=3.3

69. The refresh rate of the displayed location of the traffic was:

very unacceptable |___|___|___|___|___|___|___|___|___|___| very acceptable

$\bar{x}$=8.6

70. The location of the traffic as represented on the display differed from what was observed out of the window:

often |___|___|___|___|___|___|___|___|___|___| never

$\bar{x}$=8.0

71. Would the traffic advisory display help prevent being startled by the presence of the nearby aircraft on a parallel approach? yes 20 no 3

72. The addition of the traffic advisory display to the cockpit was:

very distracting |___|___|___|___|___|___|___|___|___|___| not at all distracting

$\bar{x}$=6.5

73. Did the traffic advisory display provide confidence in the correctness of the subsequent maneuver advisory? yes 24 no

74. Do you feel the information on the traffic advisory display is accurate enough to be used to maneuver your aircraft? yes 20 no 3

Please explain: ______________________________

____

75. Did you ever maneuver without being told to by TCAS based on the information on the traffic advisory display? yes no

yes	no
17	4

76. Were there features of the display that interfered with your use of the TCAS? yes no

Please explain ____

____

____

77. Your understanding of the operation of the traffic advisory display is:

$\bar{x}$=6.9

very limited |___|___|___|___|___|___|___|___|___|___| very complete

78. The training you received on the traffic advisory display was:

$\bar{x}$=8.2

very inadequate |___|___|___|___|___|___|___|___|___|___| very adequate

79. Would you add any information to the traffic advisory display? yes no

If so what? ____

____

____

80. What information would you take off of the traffic advisory display?

____

____

____

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16. Abstract

Pilots' use of and responses to a traffic alert and collision-avoidance system (TCAS II) in simulated air carrier line operations are described in Volume I. TCAS II monitors the positions of nearby aircraft by means of transponder interrogation, and it commands a climb or descent when conflicting aircraft are projected to reach an unsafe closest-point-of-approach within 20-25 seconds. A different level of information about the location of other air traffic was presented to each of three groups of flight crews during their execution of eight simulated air carrier flights. A fourth group of pilots flew the same segments without TCAS II equipment. Traffic conflicts were generated at intervals during the flights; many of the conflict aircraft were visible to the flight crews.

The TCAS equipment successfully ameliorated the seriousness of all conflicts; three of four non-TCAS crews had hazardous encounters. Response times to TCAS maneuver commands did not differ as a function of the amount of information provided, nor did response accuracy. Differences in flight experience did not appear to contribute to the small performance differences observed. Pilots used the displays of conflicting traffic to maneuver to avoid unseen traffic before maneuver advisories were issued by the TCAS equipment. The results indicate (1) that pilots utilize TCAS effectively within the response times allocated by the TCAS logic and (2) that TCAS II is an effective collision avoidance device.

Volume II contains the appendices referenced in Volume I, providing details of the experiment and the results, and the text of two reports written in support of the program.

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