Determination of Daytime Conspicuity of Transport Aircraft

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DETERMINATION OF DAYTIME CONSPICUITY OF TRANSPORT AIRCRAFT*

SUMMARY

The conspicuity of present-day transport aircraft was determined by measuring in daytime flight the distances at which pilots of one aircraft became aware of another DC-3 aircraft, normally painted and normally equipped, as it approached from various angles on courses which would result in collisions. Also during these collision runs, the threshold distance, ultimate distance from which a DC-3 aircraft can be seen with the naked eye, was recorded.

Two separate collision-course conditions were investigated: the uninformed phase and the informed phase. In the uninformed phase the subject pilot was unaware that he was flying a collision course. Environmental conditions which exist in the cockpit during cruising-flight situations were simulated. In the informed phase the subject pilot was aware that he was flying a collision course but did not know from which direction the other aircraft was approaching. Environmental conditions which exist in the cockpit while aircraft are flying in a terminal area were simulated.

Through the cooperation of the Air Line Pilots Association, participation of 64 subject airline pilots was obtained. Of these, 43 pilots participated in the uninformed phase and 21 pilots in the informed phase. Each pilot flew two collision runs, making a total of 128 test runs.

Four different collision courses were flown. The angles of approach of the target aircraft relative to the subject pilot's airplane were 0° (head-on), 30° left, 60° left, and 100° left. The subject pilot's average detection distance (distance separating the two aircraft on collision courses at the time the subject pilot detected the approaching airplane) obtained at the four angles of approach varied from 3.4 to 5.4 miles. The data showed no significant difference between the average detection distances obtained from the uninformed and the informed pilots. Average threshold distances varied from 10.8 to 12.4 miles.

Although relatively slow airplanes were used in this study, it is believed that the results show a definite indication of average pilot performance which can be expected. The pilot might extend his detection curve by developing better search habits, but he could not be expected to detect an airplane at threshold distance. The pilot's workload in the cockpit is too great for him to do an efficient job of searching, especially when he arrives within a highly congested terminal area. This indicates the need for an anticollision divice to aid him in searching for other aircraft. An anticollision device which would inform the pilot of the relative position of an approaching airplane at threshold distance should extend threefold the present average detection curve of the pilot. Increasing the daytime conspicuity of aircraft also should help to improve the pilot's ability to detect aircraft in his vicinity.

INTRODUCTION

The midair collision problem is becoming more acute due to the increasing number of aircraft utilizing the airways. During the five-year period from 1948 to 1953, 86 midair collisions occurred in civil flying in the United States.[1] Of these, 84 occurred during daylight or twilight hours when visibility was reported to be in excess of 3 miles. The collision hazard has been aggravated not only by the inconspicuity of present-day aircraft but by the high speeds at which they travel. Also, an F-86 fighter aircraft at a distance of 3 miles can be mistaken easily for a B-47 bomber aircraft at a distance of 10 miles because of similarity in shape. Bearing these facts in mind, it is evident that solutions to the midair collision problem are urgently needed.

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*Manuscript submitted for publication February 1957.

[1]"Mid-Air Collisions in U.S. Civil Flying," Civil Aeronautics Board of Safety Investigation, Analysis Division, September 21, 1953.

Recognizing this problem, the Technical Development Center (TDC) of the Civil Aeronautics Administration at Indianapolis, Indiana, embarked upon a collision-prevention program in 1948. The first step toward a solution to the problem was the establishment of recommendations on cockpit-visibility standards for transport-type aircraft.[2] These visibility standards were based on an evaluation of basic scientific data obtained from previous studies completed at TDC.[3, 4, 5, 6] Adoption of these standards will improve the present safety level by affording the pilots better cockpit visibility; however, improved cockpit visibility alone cannot be expected to achieve full protection against midair collisions.

The conspicuity study presented in this report is one step toward a solution which will afford substantial collision protection. The purpose of this study was to establish one basic method for evaluating collision-warning devices, other collision-prevention devices, and collision-prevention procedures, with particular emphasis on daytime flight operations. It is believed that the results obtained in this study will help to fulfill the need for basic data on the conspicuity of present-day transport aircraft and that these data can be used as basic design criteria for anticollision devices.

INSTRUMENTATION AND METHODS

Two Douglas DC-3 aircraft were used for the flight tests. These airplanes flew four different collision courses as illustrated in Figs. 1, 2, 3, and 4. A TDC pilot flew as co-pilot in the test airplane, and another TDC pilot and co-pilot flew the target airplane. The target airplane was painted similar to an average transport airplane. The fuselage was painted white, with a black stripe along each side at the height of the windows, outlined with a one-inch orange stripe.

During each test run the subject pilot's eye movements were photographed by means of a 16-millimeter motion-picture camera. The camera, utilizing a telephoto lens, was located approximately 10 feet behind the subject pilot and was focused on a convex mirror mounted on the instrument panel in front of the pilot. See Fig. 5. Any head or eye movement by the subject pilot could be seen in the wide-angle view of the convex mirror. Mounted next to the mirror was a small incandescent lamp. The lamp was flashed by the co-pilot from a remote switch at the instant the subject pilot detected the target aircraft approaching on a collision course. This permanently recorded the subject pilot's detection time on the film. To determine the film speed, the photographer placed his hand over the end of the telephoto lens for an instant at one-minute intervals. The number of frames between the blank spaces on the film revealed the film speed in frames per minute.

The collision courses investigated in this study were in the straight-and-level cruise category. When two airplanes are flying a collision course of this type, the relative bearing angle between them remains constant. To maintain this constant bearing angle, the flight path of each aircraft contained ten specific ground checkpoints. See Fig. 6. The ground checkpoints were placed at one-minute intervals. To check the accuracy with which each collision course was flown, a TDC observer in the target airplane recorded the relative bearing angle at each checkpoint by use of a telescopic sight. See Fig. 5.

[2] Thomas M. Edwards and Wayne D. Howell, "Recommendations on Cockpit-Visibility Standards for Transport-Type Aircraft," CAA Technical Development Report No. 275, February 1956.

[3] George L. Pigman and Thomas M. Edwards, "Airline Pilot Questionnaire Study on Cockpit Visibility Problems," CAA Technical Development Report No. 123, September 1950.

[4] Thomas M. Edwards and Wayne D. Howell, "A Study of Pilots' Eye Movements During Visual Flight Conditions," CAA Technical Development Report No. 179, June 1952.

[5] Thomas M. Edwards, "Development of an Instrument for Measuring Aircraft Cockpit Visibility Limits," CAA Technical Development Report No. 153, January 1952.

[6] Wayne D. Howell and Thomas M. Edwards, "Determination of Some Geometric Relationships Relative to Collision Flight Paths," CAA Technical Development Report No. 259, June 1955.

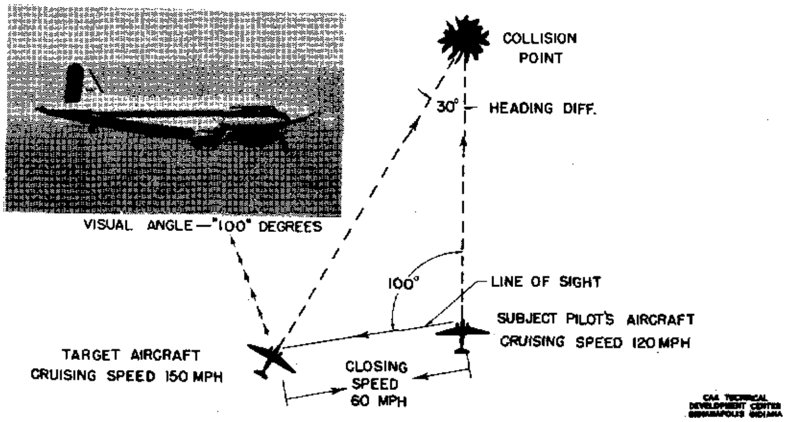

Fig. 1 Collision Case I

Flying in the subject pilot's airplane, a TDC observer who knew exactly the visual angle at which the target aircraft was approaching kept constant vigil with his naked eye until he detected it. The time of detection prior to the probable collision point was recorded and was used to compute threshold distance. The observer also recorded the time prior to the probable collision point that the subject pilot detected the target airplane. The subject pilot's detection time also was determined from the film record as a double check. Total elapsed time of each collision run between ground checkpoints 0 and 10 was recorded to determine the exact ground speed of each aircraft. This speed was used to locate both aircraft on their respective flight paths at the time the observer perceived the threshold and at the subject pilot's detection times. Knowledge of the location of each airplane permitted determination of the distance of separation at these specific times.

To control environmental variables, an attempt was made to run all tests under approximately the same brightness conditions; that is, the time of day (for relative sun location) and prevailing weather conditions, preferably CAVU.

The flight procedure followed during all of the collision flights was as follows:

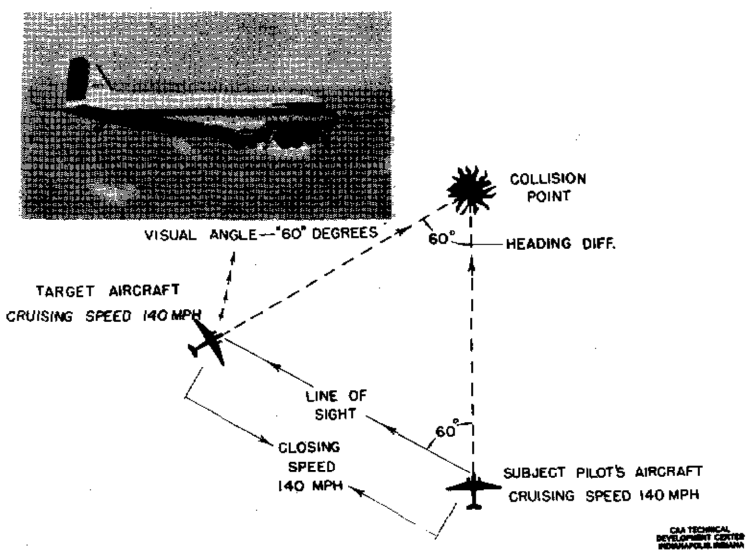

Fig. 2 Collision Case II

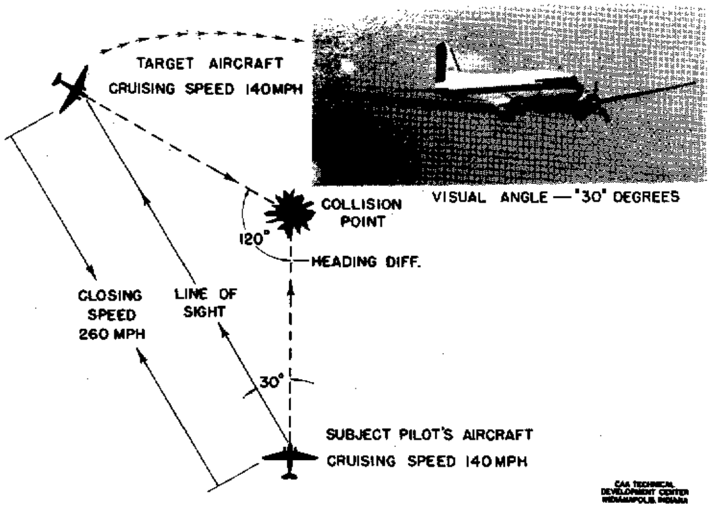

Fig. 3 Collision Case III

1. The subject pilot was requested to read thoroughly the orientation sheet[7] before each flight. Each subject pilot flew only two collision runs. The two courses flown were either collision cases I and III or II and IV, as illustrated in Figs. 1, 2, 3, and 4.

2. The TDC co-pilot indoctrinated the subject pilot in flying the DC-3 along two courses: (a) a radial very-high-frequency omnirange (VOR) course using a course-deviation indicator (CDI), and (b) a similar course using a CAA Type IV pictorial computer with a map scale of 1:500,000. See Fig. 7. The co-pilot also elaborated on points stressed on the orientation sheets.

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[7]See Appendix I.

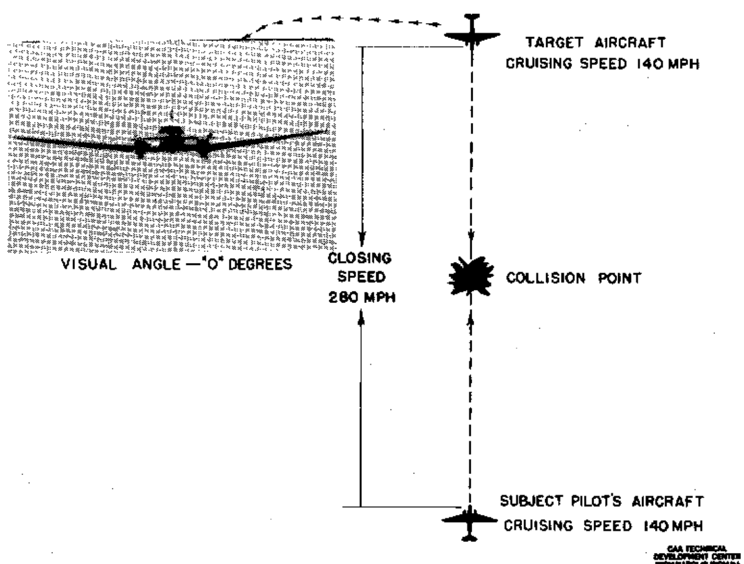

Fig. 4 Collision Case IV

Fig. 5 Flight-Instrumentation Setup

3. The subject pilot took over the controls and familiarized himself with the airplane while the target airplane flew to its starting point where it began to fly a holding pattern.
4. The TDC co-pilot directed the subject pilot to fly his airplane to its starting point and coordinated the beginning of the collision-course run with the target airplane. The TDC co-pilot called the target airplane by radio as he passed over checkpoints minus two, minus one, and zero, thereby allowing the target airplane to maneuver into position and arrive over its zero point at the same time. See Fig. 6. As the collision-course run progressed, the TDC co-pilot reported to the target airplane as he passed directly over each checkpoint. The pilot of the target airplane controlled his speed in order to arrive over the proper ground checkpoints at the same time the subject pilot's airplane arrived over its corresponding ground checkpoints.
5. In the subject pilot's airplane, the TDC observer started two stopwatches and the TDC co-pilot started one stopwatch at the instant their airplane passed over the zero checkpoint. The zero checkpoint was over a VOR station.
6. Cameramen started to photograph the subject pilot's eye movements at a prescribed time after the start of the collision-course run.
7. The TDC observer in the subject pilot's airplane stopped one stopwatch when he first sighted the target airplane (for threshold), and he stopped the second stopwatch when the subject pilot spotted the target airplane. The TDC co-pilot also flashed the recognition light beside the convex mirror at the instant the subject pilot spotted the target airplane.
8. The TDC co-pilot directed the target airplane to break off collision course as soon as it was detected by the subject pilot.
9. The TDC co-pilot stopped his stopwatch over the last checkpoint, or point of probable collision, from which actual duration of the run was determined. This ended the test run.

FILM ANALYSIS

Analysis was made of the motion-picture records of eye movements of the 64 subject pilots participating in the 128 collision runs. The film records of each run were analyzed frame by frame, and a record was kept of the total number of frames showing the subject pilot looking outside of the cockpit and the total number of frames showing the subject pilot looking inside of the cockpit. The time duration of each visual search was computed from the film

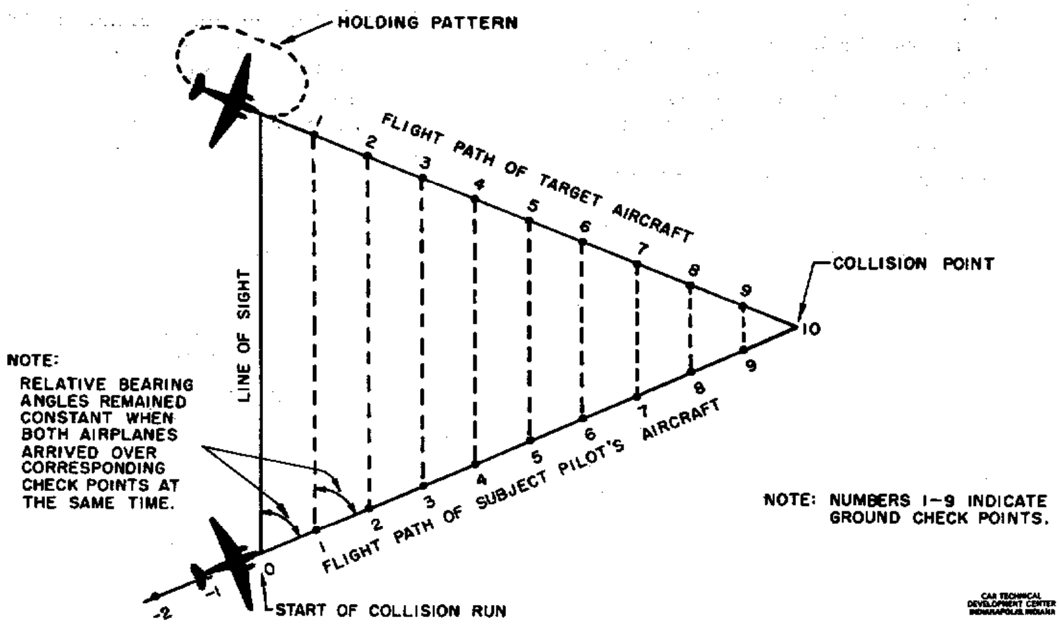

Fig. 6 Collision Flight-Coordination Diagram

speed which was approximately ten frames per second. A search was considered to be the interval of time from which the pilot's eyes fixated outside of the cockpit until his vision first returned inside the cockpit. Search frequency in looks per minute was determined by dividing the total number of searches made during a collision run by the total elapsed film time. The average search duration for each collision run was computed and multiplied by the corresponding average search frequency to obtain a search factor. For example, if the average search frequency was 11.0 looks per minute and the corresponding average search duration was 3.5

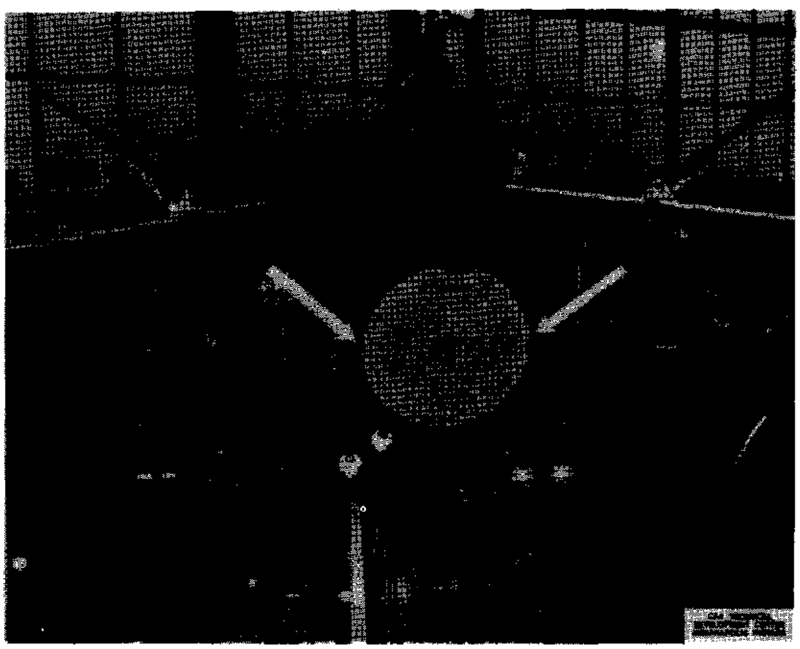

Fig. 7 Instrument Panel Showing Pictorial Computer

seconds, the search factor was 38.5; or, the subject pilot had spent on the average of 38.5 seconds of every minute looking outside of the cockpit.

The time prior to the probable collision point when the pilot first recognized the other aircraft was computed by counting the total number of photographic frames preceding the appearance of the flash of the recognition light. The change in expression on the pilot's face sometimes would indicate the instant he had spotted the other airplane. Two frames of a sample film strip showing a subject pilot spotting the other aircraft on collision course are shown in Fig. 8.

Further analysis was made of the films to determine the look frequency in each sector from which the target airplane approached. For example, if the other aircraft approached from a visual angle of 100° left of straight ahead of the subject pilot during a particular collision run, the analyst would project the film of the pilot's eye movements during that run. The analyst then selected the frame showing the subject pilot sighting the target airplane at a 100° left visual angle. This frame was used as a reference photograph. Then, as the particular film was analyzed, the number of frames which matched the reference photograph were recorded. This was the number of times the subject pilot looked 100° left prior to his detection of the target aircraft approaching from that angle. Look frequency at this visual angle was determined by dividing the total number of looks by the total elapsed film time.

The type of projector used in the analysis of the films was a Bell and Howell time and motion study projector, Design 178, Model BD. This projector allowed a frame-by-frame analysis to be made of the films, and it provided an automatic Veeder root-type frame counter.

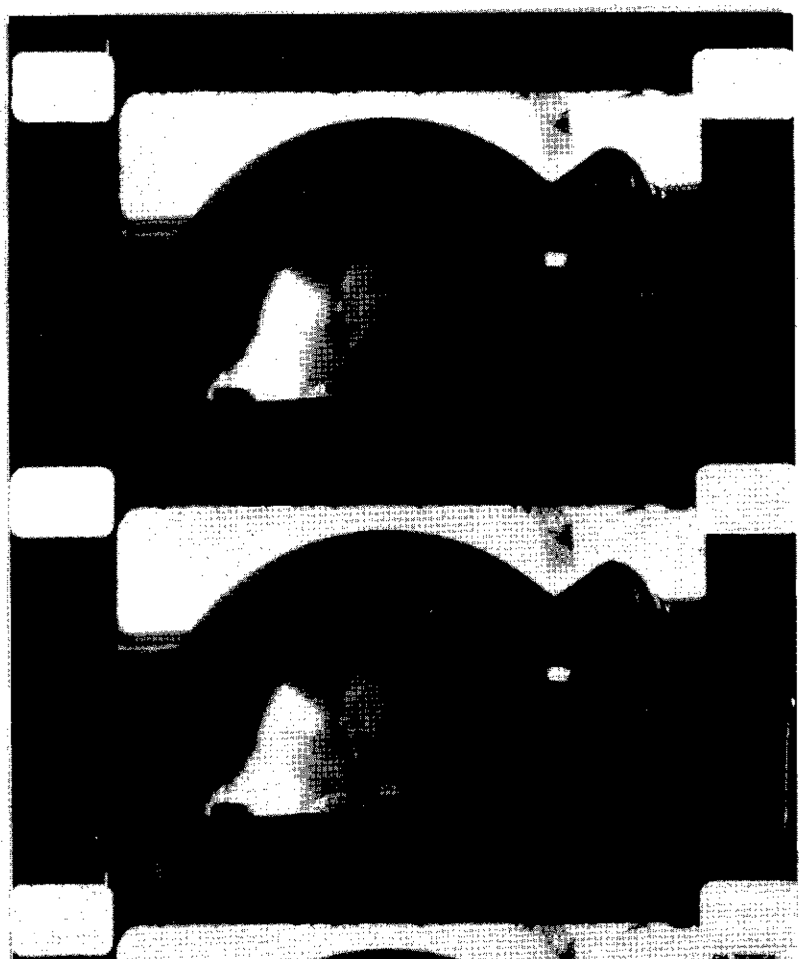

Fig. 8 Sample Pilot-Eye Movement, 16 mm Film Strip

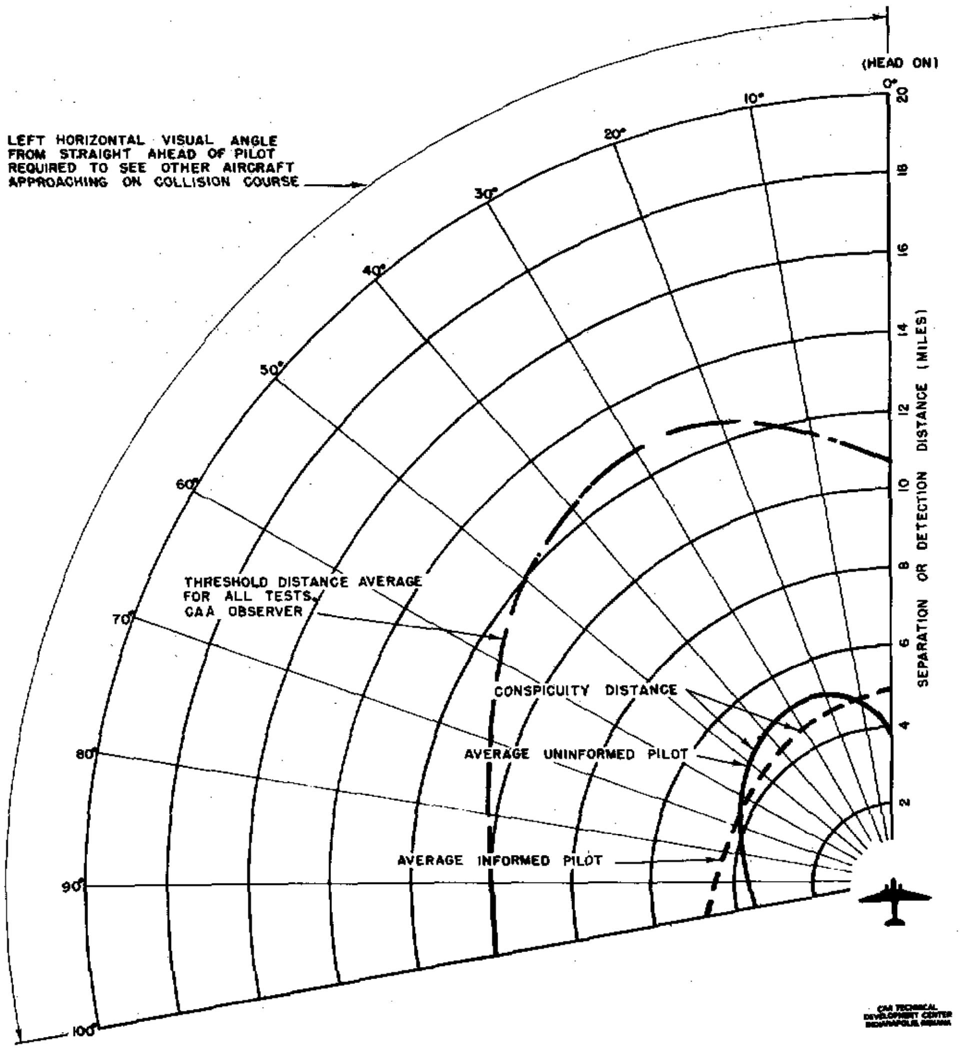

Fig. 9 Conspicuity of Present-Day Aircraft

DISCUSSION OF RESULTS

Threshold Observations.

The daytime conspicuity of present-day aircraft, specifically of the DC-3 aircraft utilized in this study, is shown in Fig. 9. The long dashed line shown in this figure represents the average threshold distance obtained on all test flights. This curve shows a maximum threshold distance of 12.4 miles at 30° visual angle. The curve then drops off to 10.8 miles at 0° visual angle and to 10 miles at 100° visual angle. The fact that a small airplane cross-sectional area or profile was presented to the threshold recorder is considered to be a contributing factor toward a lower threshold in the head-on collision case. The profile area at 0° visual angle is approximately one-half the profile area at 30° visual angle. Although the profile areas presented during collision cases I and II or at visual angles of 100° and 60° were greater than that at 30° visual angle, the threshold-distance values obtained at 100° and 60° actually were less than at 30°. This ambiguity was caused partially by the presence of uncontrollable variables such as varying background and ambient light conditions caused by clouds or haze. For example, under certain light background conditions with considerable profile area showing as in collision cases I and II, when more of the white top of the airplane fuselage was visible, the white would blend in with the background and tend to camoflage the airplane, thereby producing a low threshold. Under the same conditions a higher threshold would be recorded in collision case III, when less profile area was visible along with less white fuselage

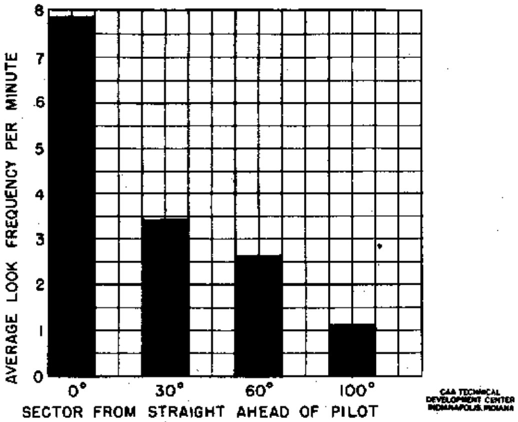

Fig. 10 Look-Distribution Chart (Uninformed Phase)

top. This made the airplane appear darker; therefore, it was more conspicuous. Negative contrast conditions (aircraft darker than background) produced higher threshold-distance values than did positive contrast conditions (airplane lighter than background). During collision run No. 21, Table I, collision case III, the visual threshold of the target airplane was recorded at 19.6 miles. This was next to the greatest threshold distance recorded, and it occurred during negative contrast conditions. This threshold was recorded under conditions of a very high, solid overcast. This high overcast eliminated any glaring sun reflections in the cockpit, thereby aiding the recorder in seeing the target airplane.

Uninformed Pilot's Observations.

The average uninformed subject pilot's detection curve (solid line, Fig. 9) shows the average detection distance obtained from the four collision cases to be as follows: 3.4 miles at head-on; 5.4 miles at 30°; 4.3 miles at 60°; and 3.5 miles at 100°. The detection distance decreases at 0° visual angle or head-on collision case because of the small airplane-profile area confronting the subject pilot. The curve reaches a maximum of 5.4 miles at 30°, then gradually decreases to a value of 3.5 miles at 100°. It is believed that this gradual reduction in average detection distance in the 30° to 100° sector is due to the subject pilot's search habits which revealed a low look frequency in this area. This fact is shown in the look-distribution chart for uninformed pilots, Fig. 10. The average uninformed pilot looked toward the extreme left less frequently, thereby allowing the observed airplane to fly closer before detection.

Informed Pilot's Observations.

The average informed subject pilot's detection curve (short dashed line, Fig. 9) shows the average detection distance obtained from the four collision cases to be as follows: 5.0 miles head-on; 4.5 miles at 30°; 4.2 miles at 60°; and 4.8 miles at 100°. Comparing these results with those obtained from the uninformed phase, the informed pilot increased his average performance level at 0° from 3.4 miles to 5.0 miles, decreased it from 5.4 miles to 4.5 miles at 30°, maintained the same performance level at 60°, and increased it from 3.5 miles to 4.8 miles at 100°.

The subject pilot, informed that he was flying a collision course, tended to distribute his looks more evenly over his visual area as indicated by the increase in look frequency in the 60° and 100° sectors, with a corresponding decrease at 0° when comparing Figs. 10 and 11. Even though the look frequency dropped off slightly in the 0° sector, the average detection distance increased. This indicates that the average informed subject pilot was doing a somewhat more efficient job of seeing during each look in this sector; that is, the pilot's eyes were fixating on one spot in this sector for a longer period of time before moving on to another. Eye fixations also were longer at 100° which was the point of extreme head movement. The pilot, in making his systematic search, would turn his head to approximately 100° left, stop, and hesitate for a moment before continuing his search back to the right.

A pilot's frequency of looks outside of the cockpit may be high, along with a long average length of each look; but unless the pilot allows his eyes to fixate long enough in one spot for his brain to perceive what he is seeing, his eye can pass over a small target without his actually perceiving it. The lapse of time for perception between the eye and the brain may be as long as

TABLE I

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
				Uninformed Phase				
1	0	11.50	:03	0.20	6.38	1.19	7.59	CAVU, few cirrus clouds for back-ground
2	No collision course				2.59	0.75	1.94	
3	60	18.00	:12	2.00	4.79	2.13	10.20	
4	No collision course				9.64	1.38	13.30	
5	100	8.00	No sighting		8.24	2.12	17.47	CAVU, haze
6	30	17.00	:17	5.00	9.72	1.87	18.18	
7	0	9.00	:05	0.40	5.06	2.28	11.54	
8	No collision course				5.43	2.21	12.00	Above clouds and haze
9	60	11.75	2:36	6.50	2.96	5.21	15.42	
10	100	10.00	No sighting		7.43	4.35	32.32	
11	No collision course				10.87	1.59	17.28	CAVU, slight haze
12	30	11.00	:23	3.00	8.27	3.27	27.04	
13	0	7.10	:05	0.85	10.60	1.62	17.17	CAVU, haze
14	No collision course				9.29	2.14	19.88	
15	60	6.00	:45	2.00	12.93	1.97	25.47	CAVU, haze
16	100	7.25	1:15	1.60	4.38	4.97	21.77	Broken clouds at 15,000 feet, extreme haze
17	30	4.50	:10	1.40	6.14	3.18	19.53	
18	0	8.50	:30	2.60	9.58	2.46	23.57	CAVU above haze, reflectance off
19	60	18.20	3:51	10.00	7.38	3.22	23.76	
20	100	9.00	2:48	3.20	10.56	2.39	25.24	High cirrus overcast
21	30	19.60	1:19	7.00	10.46	2.62	27.41	

TABLE I (continued)

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
22	0	10.00	:40	3.00	9.96	3.63	36.16	CAVU, slight haze
23	60	9.50	1:23	4.00	6.84	4.41	30.16	
24	0	6.00	:24	2.00	8.78	2.04	17.91	Scattered clouds at 5000 feet, visibility poor
25	60	12.60	No sighting		7.57	2.63	19.91	
26	100	10.00	No sighting		11.91	1.97	23.46	Scattered clouds at 5000 feet
27	30	16.00	1:40	6.70	11.99	2.45	29.38	
28	0	6.00	:41	3.50	6.39	2.63	16.81	Broken clouds at 9000 feet, few clouds in background
29	60	10.50	:22	2.00	6.97	5.05	35.20	
30	100	10.00	2:45	3.00	17.56	1.88	33.01	CAVU, haze
31	30	2.50	:20	2.50	8.50	3.56	30.26	
32	0	2.00	:17	2.00	8.96	3.45	30.91	Broken clouds at 7000 feet, bad haze
33	60	10.00	:03	1.00	8.39	3.50	29.37	
34	100	10.00	2:30	2.30	3.68	1.59	5.85	Visibility good, few scattered cirrus clouds as background
35	30	20.00	2:21	9.00	4.35	1.49	6.48	
36	60	8.50	No sighting		4.09	1.88	7.69	High cirrus clouds above haze, good visibility
37	0	13.00	:05	1.00	7.03	2.03	14.27	
38	100	4.00	No sighting		2.94	1.04	3.06	12,000-foot overcast, poor visibility, bad haze
39	30	8.50	No sighting		1.25	1.37	1.71	
40	60	4.00	:15	1.25	12.13	2.32	28.14	7000-foot overcast, observed airplane below haze
41	0	14.00	:23	2.50	8.26	1.60	13.22	

TABLE I (continued)

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
42	100	10.00	5:15	6.50	11.17	2.35	26.25	7000-foot overcast
43	30		:21	2.00	8.56	3.75	32.10	
44	60	9.10	1:39	3.70	7.18	4.11	29.51	8000-foot overcast, visibility good above smoke
45	0	17.50	1:44	8.00	5.21	6.17	32.15	
46	100	12.80	2:36	3.80	6.20	8.32	51.58	8000-foot solid overcast
47	30	7.20	1:01	5.00	5.07	10.49	53.18	
48	60	12.00	:51	2.50	No film record			8000-foot overcast
49	0	7.00	:23	2.10	10.24	4.08	41.78	
50	100	12.90	1:12	1.70	10.65	3.98	42.39	CAVU
51	30	10.80	1:14	4.90	9.74	4.46	43.44	CAVU
52	60	13.70	2:26	5.90	No film record			CAVU
53	0	13.20	:49	4.00	14.09	2.11	29.73	CAVU
54	100	10.10	3:59	5.10	5.70	7.15	40.76	CAVU
55	30	17.30	2:09	9.30	4.69	10.90	51.12	CAVU
56	60	18.70	5:25	13.90	6.75	5.78	39.02	CAVU
57	0	13.10	1:45	8.40	4.73	8.96	42.38	CAVU
58	100	12.40	1:59	3.70	No film record			15,000-foot overcast
59	100	12.00	:57	1.20	11.61	2.30	26.70	CAVU
60	30	17.10	2:45	11.60	14.06	2.34	32.90	CAVU
61	60	14.00	2:33	6.30	8.36	5.11	42.72	CAVU
62	0	13.00	1:22	6.40	6.23	7.54	46.97	CAVU
63	100	10.60	1:56	2.40	10.80	3.09	33.37	CAVU
64	30	13.20	1:13	5.30	10.67	2.93	31.26	CAVU

TABLE I (continued)

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
65	60	13.00	1:19	3.20	11.30	3.40	38.42	High overcast, 9000 feet
66	0	9.20	:44	3.70	11.21	3.21	35.98	High overcast, 9000 feet
67	100	9.50	3:35	4.30	8.63	3.51	30.29	High overcast, 9000 feet
68	30	15.20	1:09	4.80	6.36	4.82	30.66	High overcast, 9000 feet
69	60	14.40	2:41	6.20	7.19	5.37	38.61	High overcast, 9000 feet
70	0	9.90	:31	2.40	5.33	8.17	43.55	High overcast, 9000 feet
71	100	13.50	6:04	7.80	10.94	3.57	39.06	CAVU
72	30	14.90	1:47	7.40	10.06	3.27	32.90	CAVU
73	60	11.00	:50	2.30	4.13	5.12	21.15	CAVU
74	0	13.40	1:11	6.00	6.71	5.19	34.82	CAVU
75	100	12.60	:06	0.20	13.05	2.71	35.37	CAVU
76	30	22.20	:12	0.90	10.75	2.65	28.49	CAVU
77	60	9.50	:39	1.50	7.23	4.50	32.54	CAVU
78	0	Bad collision run						
79	100	12.90	2:43	3.90	8.50	3.91	33.24	Visibility good
80	30	14.50	:46	3.70	7.55	4.47	33.75	Visibility good
81	60	11.50	:32	1.50	8.97	5.05	45.30	Visibility good
82	0	11.90	:44	4.10	8.79	5.08	44.65	Visibility good

TABLE I (continued)

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
				Informed Phase				
83	100	5.70	No detection		4.81	10.61	51.03	Haze
84	30	12.90	:46	3.60	4.73	10.96	51.84	Haze
85	60	7.00	:55	2.90	5.40	9.68	52.27	Haze
86	0	9.30	:20	2.30	5.97	8.64	51.67	Haze
87	100	5.80	:54	3.60	9.98	4.13	41.22	Haze
88	30	5.30	:17	1.60	10.30	4.05	41.72	Haze
89	60	11.70	3:15	7.99	10.79	3.36	36.25	CAVU
90	0	11.00	1:42	8.29	7.99	4.09	32.68	CAVU
91	100	8.35	4:42	5.90	8.40	3.73	31.33	CAVU
92	30	15.00	2:23	10.10	10.56	2.93	30.94	CAVU
93	60	8.20	1:25	3.75	7.46	5.50	41.03	CAVU
94	0	9.20	:48	4.03	5.10	7.96	40.60	CAVU
95	100	11.80	:33	0.70	9.50	4.55	43.23	Haze
96	30	7.55	:29	2.30	9.10	3.08	28.03	Haze
97	60	7.08	:14	0.79	5.32	8.00	42.56	Haze
98	0	8.60	:29	2.75	5.60	8.68	48.61	Haze
99	Poorly coordinated collision run							
100	30	8.60	:52	2.40	9.75	5.83	56.84	Haze
101	60	11.90	1:42	4.20	7.30	6.71	48.98	Haze
102	0	13.90	1:52	8.70	6.34	7.77	49.26	Haze
103	100	5.10	1:33	2.30	4.92	7.93	39.02	CAVU

TABLE I (continued)

TEST RESULTS

Test No.	Visual Angle (degrees)	Threshold Distance (miles)	Detection Time* (minutes: seconds)	Separation Distance (miles)	Look Frequency (looks per minute)	Average Length of Look (seconds)	Look Factor (seconds)	Weather
104	30	8.50	:42	2.00	5.78	7.81	45.14	CAVU
105	60	9.10	:10	0.50	11.45	2.76	31.60	CAVU
106	0	6.40	:33	2.70	8.32	5.37	44.68	CAVU
107	100	10.50	3:57	7.75	7.90	6.13	48.43	CAVU, slight haze
108	30	4.81	:35	2.40	6.92	6.46	44.70	CAVU, slight haze
109	60	8.60	2:08	5.89	7.56	6.54	49.44	CAVU
110	0	15.70	:50	4.03	5.28	10.18	53.75	CAVU
111	100	15.00	6:29	9.65	No film record			CAVU
112	30	17.00	1:55	9.00	9.30	4.04	37.55	CAVU
113	60	9.40	1:39	4.45	4.42	7.36	32.53	CAVU
114	0	10.56	1:49	9.65	7.13	7.11	50.69	CAVU
115	100	11.80	4:40	7.15	7.87	4.72	37.15	CAVU
116	30	8.70	:57	4.40	8.62	5.03	43.36	
117	60	11.40	1:59	5.15	9.17	4.12	37.78	CAVU, slight haze
118	0	14.66	1:05	5.00	7.28	5.89	42.88	CAVU, slight haze
119	100	11.10	2:07	3.00	6.12	3.68	22.52	CAVU, slight haze
120	30	6.50	:49	3.80	7.60	3.75	28.50	CAVU, slight haze
121	60	15.00	1:42	4.30	6.88	6.05	41.62	CAVU, slight haze
122	0	13.40	:35	3.20	4.02	12.76	51.30	CAVU, slight haze
123	100	10.04	2:02	2.80	7.32	4.75	34.77	More haze
124	30	6.80	1:18	6.10	7.83	4.20	32.89	More haze
125	60	9.00	1:12	3.30	7.26	5.24	38.04	Cloudy background
126	0	3.70	:47	2.20	6.94	6.64	46.08	Cloudy background
127	100	6.70	No detection		7.14	4.77	34.05	Cloudy
128	30	16.90	1:23	6.30	7.35	4.88	35.87	Cloudy background

*Detection time is time from detection to point of probable collision.

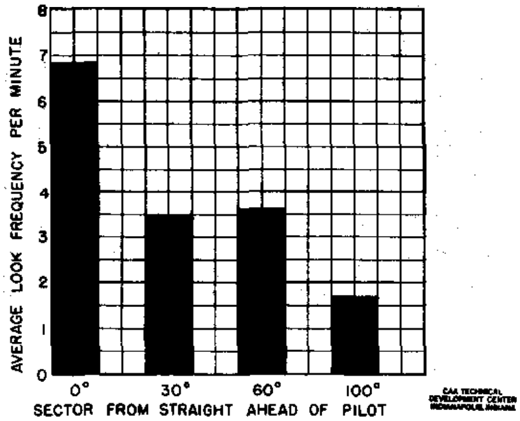

Fig. 11 Look-Distribution Chart (Informed Phase)

0.3 second.[8] Even after the impulse reaches the brain it still can take up to 0.5 second more before the pilot recognizes the target. For example, in run No. 83 the look frequency was 4.81 looks per minute at an average of 10.61 seconds per look, resulting in the informed pilot's looking out 51.03 seconds of every minute. Yet, the pilot failed to detect the approaching airplane.

General Observations.

The detection distances obtained from the subject pilots and the threshold recorder, in both the informed and uninformed phases, varied considerably. See Table II and Figs. 12, 13, and 14. In a few specific cases (seven in the uninformed phase and two in the informed phase) the subject pilots failed completely to detect the target airplane. At the other extreme, an uninformed subject pilot detected the target aircraft at 13.9 miles. See test No. 56, Table I. The wide variance in results also is illustrated by Figs. 15, 16, and 17, where the standard deviation from the mean is plotted for both the subject pilot and threshold distances recorded in the informed and uninformed phases. The figures show that there was more deviation from the mean in threshold-distance recordings than in subject pilot detection-distance recordings. Threshold recordings were affected much more easily by any slight change in atmospheric conditions such as background, lighting conditions, or the presence of haze, because the aircraft at this distance appears so small compared to size of the aircraft at the subject pilot's detection distance. The aircraft at threshold could be visible for one instant of time, and it then could disappear suddenly due to a sudden change in conditions. The wide variance in detection distances obtained from the subject pilots was caused primarily by the differences in their search habits. Some pilots were very deliberate and efficient while searching for other aircraft; consequently, they detected the observed aircraft at a greater distance than did the subject pilot who, in most cases, was spending as much time in looking but was not as efficient. In a few cases in the uninformed phase, the subject pilot spent most of his time looking at the instruments, which resulted in very near detection distance or none. It is believed that regardless of the varying results obtained in this study, each collision run was representative of actual conditions which occur or could occur in civil flying today.

The mean detection distances obtained for the subject pilot and threshold observer were converted into time prior to collision point. They are plotted in Figs. 18 and 19. Figure 18 shows that the average uninformed pilot had only 44 seconds to avoid a collision with the observed airplane approaching from head-on as compared to 64 seconds for the average informed pilot. The head-on collision case is critical because it represents the highest rate of closure and the approaching aircraft is most difficult to detect because of its small profile area. Figure 19 shows how much more time a pilot would have to avoid a collision if he could detect the approaching airplane at threshold.

The data show that regardless of whether the subject pilots were informed or uninformed that they were flying a collision course, there was little significant difference in their average

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[8] Brig. Gen. Joseph D. Croft Caldara, USAF, "Aircraft Demands Exceed Pilot Capability," Aviation Week, Vol. 64, No. 4, January 23, 1956, p. 48.

TABLE II

DETECTION DISTANCES AND AVERAGES

	0° Visual Angle Threshold	0° Visual Angle Subject Pilot	30° Visual Angle Threshold	30° Visual Angle Subject Pilot	60° Visual Angle Threshold	60° Visual Angle Subject Pilot	100° Visual Angle Threshold	100° Visual Angle Subject Pilot
Uninformed Pilots	11.50	0.20	17.00	5.00	18.00	2.00	8.00	0.00
	9.00	0.40	11.00	3.00	11.75	6.50	10.00	0.00
	7.10	0.85	4.50	1.40	6.00	2.00	7.25	1.60
	8.50	2.60	19.60	7.00	18.20	10.00	9.00	3.20
	10.00	3.00	16.00	6.70	9.50	4.00	10.00	0.00
	6.00	2.00	20.00	9.00	12.60	0.00	10.00	3.00
	6.00	3.50	8.50	0.00	10.50	2.00	10.00	2.30
	13.50	1.00	7.20	5.00	10.00	1.00	4.00	0.00
	14.00	2.50	10.80	4.90	8.50	0.00	10.00	6.50
	17.50	8.00	17.30	9.30	4.00	1.25	12.80	3.80
	7.00	2.10	17.10	11.60	9.10	3.70	12.90	1.70
	13.20	4.00	13.20	5.30	12.00	2.50	10.10	5.10
	13.10	8.40	15.20	4.80	13.70	5.90	12.40	3.70
	13.00	6.40	14.50	7.40	18.70	13.90	12.00	1.20
	9.20	3.70	22.20	0.90	14.00	6.30	10.60	2.40
	9.90	2.40	14.50	3.70	13.00	3.20	9.50	4.30
	13.40	6.00		2.00	14.40	6.20	13.50	7.80
	11.90	4.10			11.00	2.30	12.60	0.20
					9.50	1.50	12.90	3.90
					11.50	1.50		
Average	10.70	3.40	14.30	5.43	11.80	4.25	10.40	3.45
Informed Pilots	9.30	2.30	12.90	3.60	7.00	2.90	5.70	0.00
	11.00	8.30	5.30	1.60	11.70	8.00	5.80	3.60
	9.20	4.00	15.00	10.10	8.20	3.75	8.35	5.90
	8.60	2.75	7.55	2.30	7.08	0.80	11.80	0.70
	13.90	8.70	8.60	2.40	11.90	4.20	5.10	2.30
	14.66	5.00	8.50	2.00	11.40	5.15	10.50	7.75
	15.70	4.00	4.80	2.40	8.60	5.89	15.00	9.65
	10.56	9.65	17.00	9.00	9.40	4.45	11.80	7.15
	13.40	3.20	8.70	4.40	15.00	4.30	11.10	3.00
	3.70	2.20	6.50	3.80	9.00	3.30	10.04	2.80
			6.80	6.10			6.70	0.00
			16.91	6.33				
Average	11.00	5.00	9.88	4.50	9.90	4.20	9.30	4.80
Total Average Informed and Uninformed	10.80	3.60	12.40	5.03	11.20	4.20	10.00	4.00

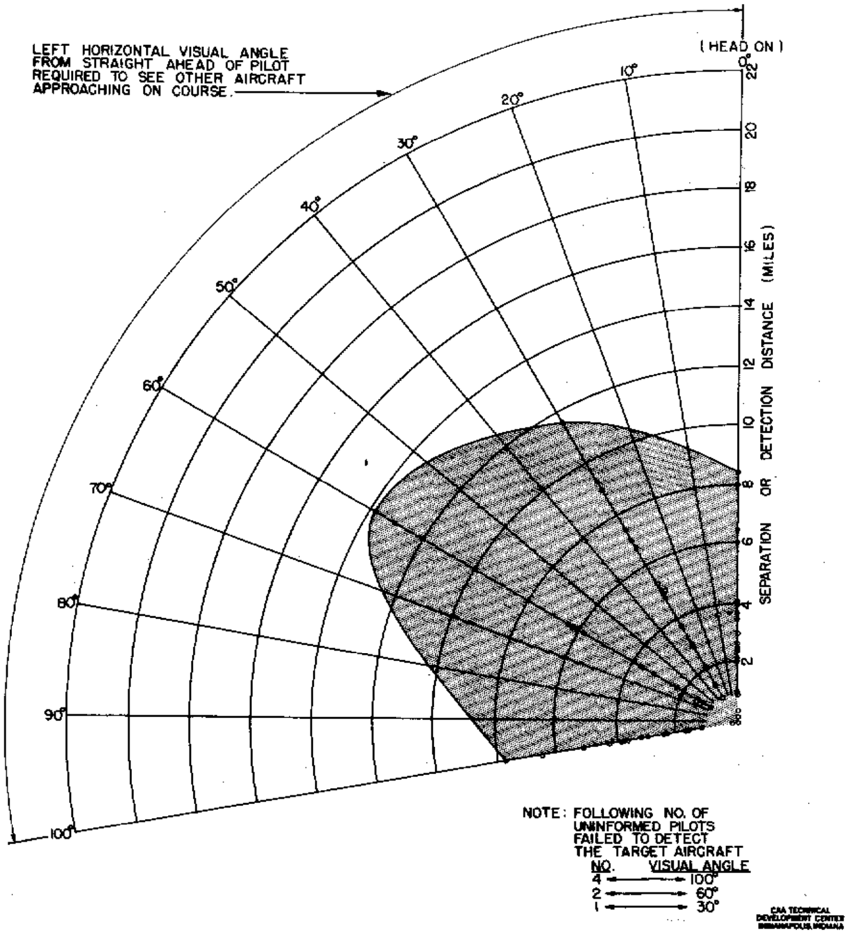

Fig. 12 Detection Distances (Uninformed Phase)

detection distance except at 0° and 100°. This indicates that the pilot was being as efficient as possible in searching for other aircraft, regardless of whether he was aware of another airplane on a collision course. The workload in the cockpit undoubtedly limits his look performance. This is a situation which occurs in day-to-day flying. Although the average pilot can develope better search habits, he cannot be expected to detect an airplane at threshold distance. The results indicate that a pilot's knowledge that he is on a collision course is not enough. He also must know the direction of approach of the oncoming airplane. Thus, an anticollision device must detect an approaching airplane at threshold, and it must inform the pilot of its relative direction. Because the test results show that the ratio of threshold to the pilot's average detection distance is 3:1, there is promise that such a proximity device would increase threefold the pilot's average expected detection time.

The aircraft used in this study were Douglas DC-3 airplanes flying at speeds of approximately 140 mph. In applying these data to jet aircraft, which fly at much higher speeds and some of which have less profile area, shorter detection distances for the pilot might be expected. How much less distance cannot be determined accurately without actually repeating this investigation with faster airplanes. It is reasonable to assume, however, that if aircraft which approached each other at four or five times the speed of a DC-3 were used in such a study and if they were smaller in profile area, the average detection distance would not allow the pilot sufficient time to react and maneuver his aircraft to avoid collision. If total reaction

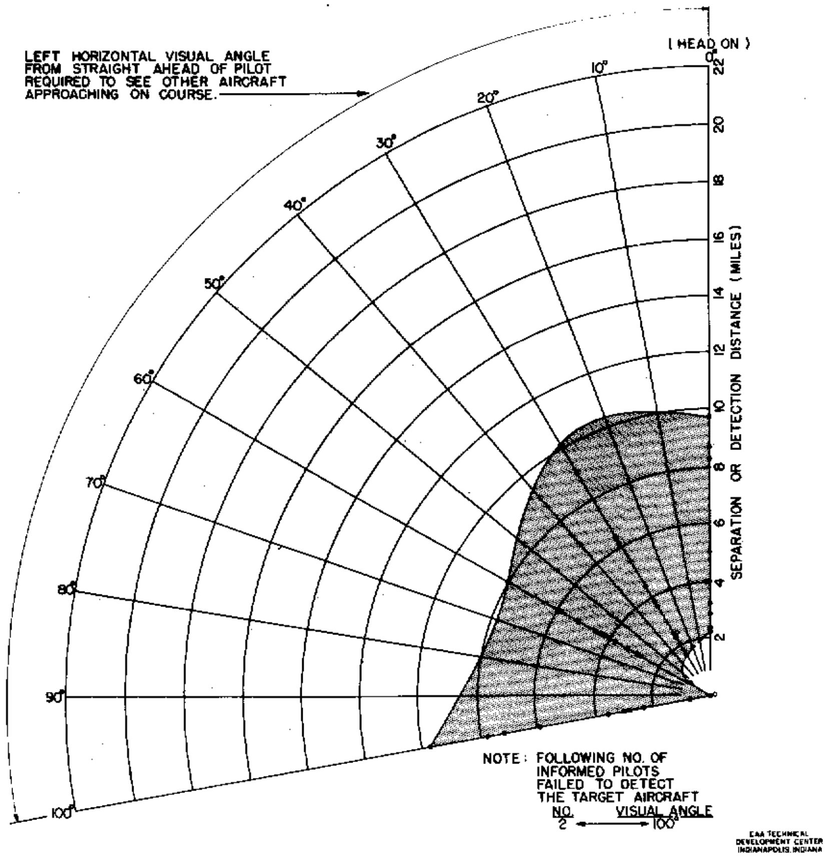

Fig. 13 Detection Distances (Informed Phase)

time is assumed to be 15 seconds,[9] including recognition time, decision time, human motor reaction, and airplane response time, and if two airplanes were approaching each other head-on at 500 mph each (1000-mph closing velocity, or 1 mile ever 3.6 seconds) detection would have to occur at 4.2 miles separation to avoid collision.

This study has shown not only that airplanes need to be made more conspicuous but that the midair collision problem is growing more critical as higher speed aircraft come into use. The rate of closure for converging aircraft will exceed the limits within which human visual capabilities can insure collision avoidance; therefore, it is necessary that the pilot be given assistance through the use of some type of collision-warning device.

CONCLUSIONS

1. Aircraft can be seen at the greatest distance under negative contrast conditions (dark aircraft against a light background) when a very high overcast is present.
2. Pilots could improve their ability to detect other aircraft on a collision course by developing better search habits; but, due to workload in the cockpit and other factors, the pilot could not be expected to detect an aircraft at threshold distances.
3. There is a need for a collision-warning device to aid the pilot in searching for other aircraft. A device which would detect an aircraft approaching on a collision course at

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[9] Lt. Col. George O. Emerson, USAF, Capt. Robert D. Metcalf, USAF, and Harold C. Glover, "The Inadequacy of Visual Search in Avoiding Mid-Air Collision," Wright Air Development Center Technical Note 56-145, March 1956.

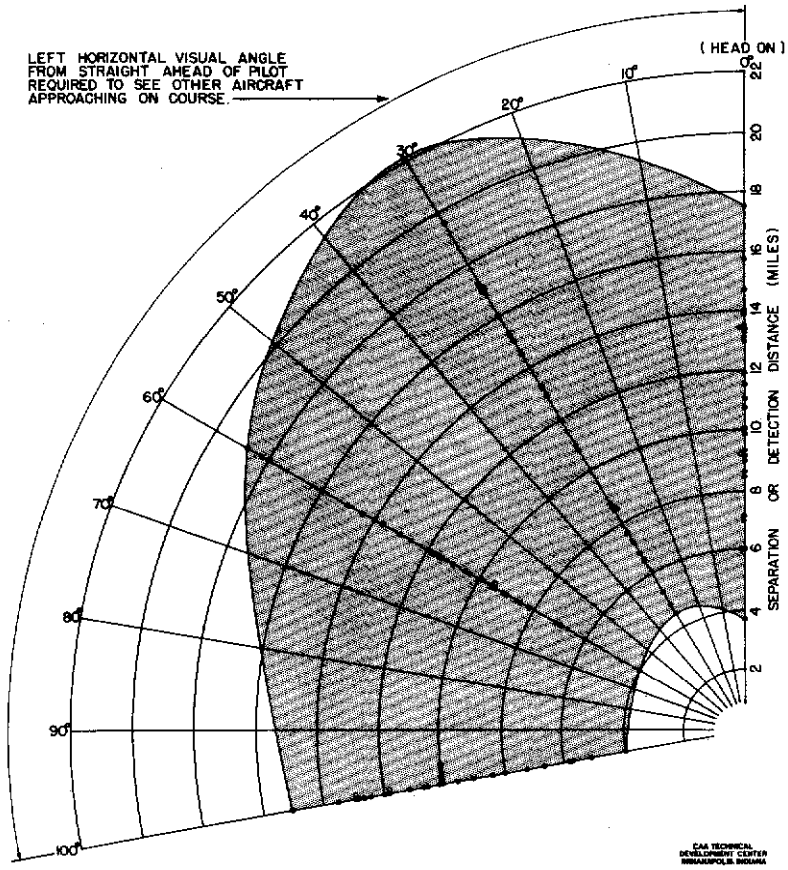

Fig. 14 Threshold Distances (All Runs)

threshold and indicate the direction of approach could extend effectively the present average detection curve of the pilot. Informing a pilot only that an airplane within his proximity is a potential hazard is insufficient to aid effectively in visual detection. He must be given the direction of approach of the potential hazard.

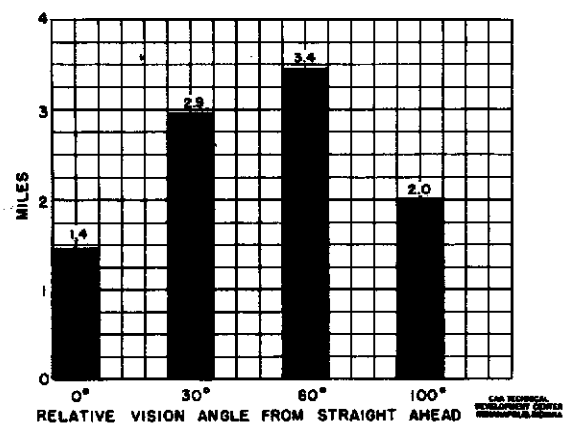

Fig. 15 Standard Deviation from the Mean for Subject Pilots (Uninformed Phase)

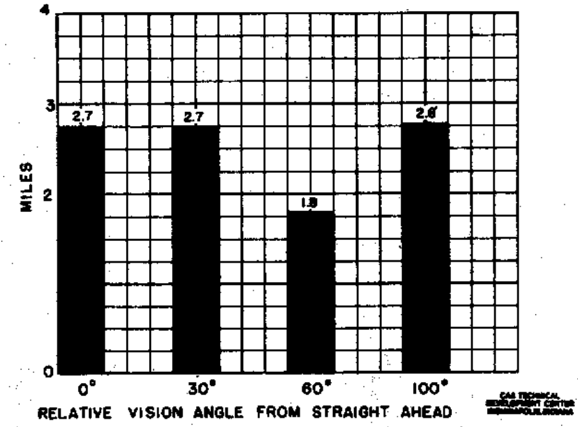

Fig. 16 Standard Deviation from the Mean for Subject Pilots (Informed Phase)

4. The results obtained in this study show a definite indication of expected average performance of the pilot in detecting aircraft approaching on a collision course while he is performing normal cockpit duties.

5. Because aircraft used in this study flew at relatively slow speeds, the average detection distance of the pilot would be expected to be much less in similar tests involving aircraft such as jets with much higher speeds and smaller profile area. This indicates that as the speeds of aircraft become increasingly greater, the rate of closure for converging aircraft will exceed the limits within which human visual capabilities can insure collision avoidance.

6. Aircraft need to be made more conspicuous.

ACKNOWLEDGEMENT

Acknowledgement is made of the assistance of Messrs. Ted Linnert, Carl Eck, and Bob Stone of the Air Line Pilots Association who arranged for cooperation of subject pilots from the following airlines: Trans World, American, United, Eastern, United Flying Tiger, and Lake Central; and of all the pilots who participated as subjects, without whom this study would not have been possible.

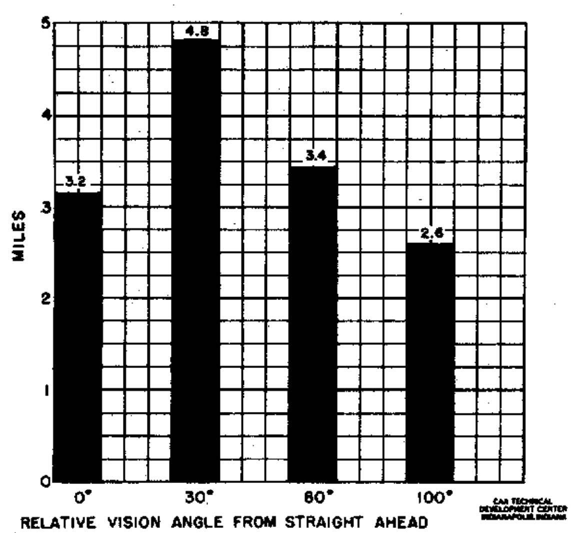

Fig. 17 Standard Deviation from the Mean for Threshold (All Tests)

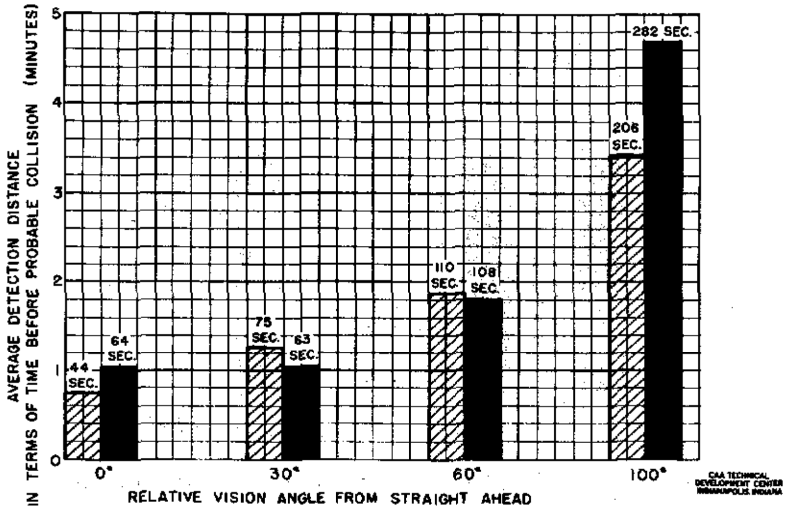

Fig. 18 Detection Times of Average Informed and Uninformed Pilots

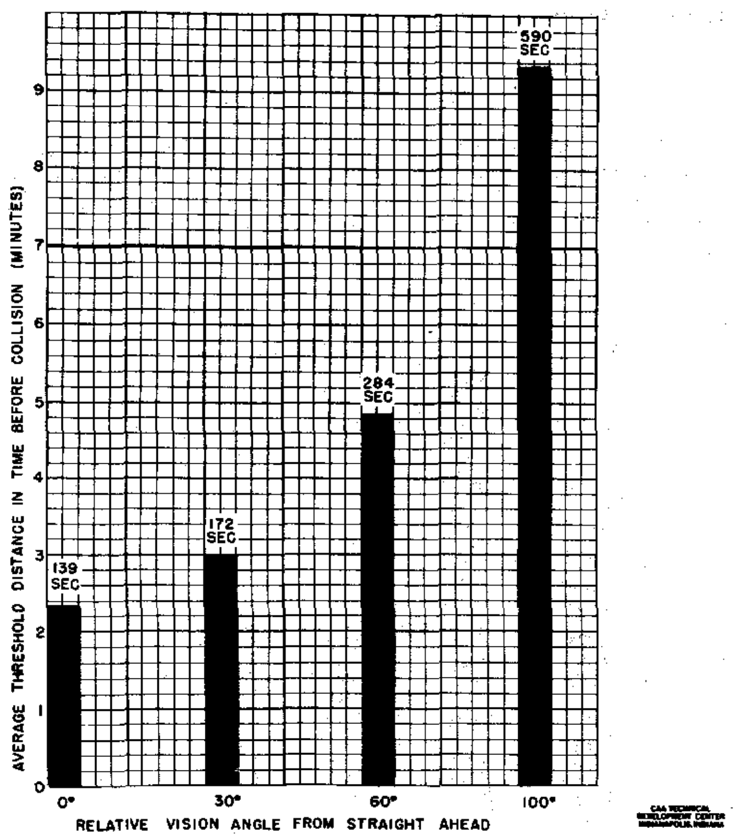

Fig. 19 Detection Times from Average Threshold Distances (All Tests)

APPENDIX I

ORIENTATION SHEET I (UNINFORMED PHASE)

PRELIMINARY INFORMATION FOR AIRLINE PILOTS PARTICIPATING IN COMPARATIVE EYE FIXATION TIME TESTS OF VOR COURSE-DEVIATION INDICATOR AND PICTORIAL COMPUTER

At this stage of the project, it is necessary to obtain certain information from experienced airline pilots. With the approval of the Air Line Pilots Association, we therefore ask for your assistance.

The objective of this test is to compare the amount of eye-fixation time required to perform all normal duties while flying a selected course, using first the standard VOR course-deviation indicator instrument and then the pictorial computer. This time study will be accomplished by using special photographic techniques.

Administration policy requires that both pilot seats be occupied by TDC pilots for all takeoffs and landings, but immediately after takeoff you will move into the pilot's seat and fly the airplane. The TDC co-pilot will give you all of the necessary instructions and correlate the airplane position with a ground station for precision checks. The TDC co-pilot will handle all radio contacts.

These tests will be performed in the vicinity of the Indianapolis airport. In addition to the regular traffic, there may be additional TDC flight tests in progress; therefore, in the interest of safety, it will be necessary for you to notify the co-pilot of any aircraft you may see and the co-pilot will likewise notify you of any aircraft he may see.

After completion of the test, the TDC pilot will change places with you for the landing.

We appreciate your participation in this study. Any comments that you desire to make may be made in the following space.

Note: The uninformed phase was intended to simulate actual cockpit conditions which are present during cruising flights between cities.

ORIENTATION SHEET II (INFORMED PHASE)

PRELIMINARY INFORMATION FOR AIRLINE PILOTS PARTICIPATING IN AIRCRAFT CONSPICUITY STUDY

During this phase of the conspicuity project, it is necessary to obtain data from experienced airline pilots. With the approval of the Air Line Pilots Association, we therefore ask for your assistance.

Our main objective is to determine the conspicuity of present-day aircraft by measuring the distance at which you as a subject pilot are able to see another aircraft. The other aircraft will be flying on a collision course with the TDC DC-3 that you will be flying. The direction of approach of the other aircraft will be deliberately withheld.

While flying these two collision courses, you will be required to hold airspeed, heading, and altitude to very close tolerances. Also, please try to maintain the same vigilance outside the cockpit as you would while flying under normal operations near the vicinity of an airport. Photographs will be taken of your eyes to determine how much time you spend looking outside the cockpit as compared to the time spent looking at the instruments.

Since there will be other aircraft in the vicinity besides the airplane with which you are on collision course, please notify the TDC co-pilot immediately of all aircraft that you happen to see.

Administration policy requires that both pilot seats be occupied by TDC pilots for all takeoffs and landings, but immediately after takeoff you will move into the pilot's seat and fly the airplane. The TDC co-pilot will give you all of the necessary instructions and correlate the airplane position with the other aircraft for precision checks. The TDC co-pilot will handle all radio contacts.

After completion of the test, the TDC pilot will change places with you for the landing.

Since the results of these tests will be presented in statistical form only, they will not be identified with the subject pilot. This study is merely a step toward finding a solution to the ever increasing midair collision problem.

We appreciate your participation in this study. Any comments that you desire to make may be made in the following space.

Note: The informed phase was intended to simulate actual cockpit conditions which are present while aircraft are flying in a terminal area when the pilot is more alert to the possible presence of other aircraft.