An Investigation of Some Parameters Related to Midair Collisions of Aircraft

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SUMMARY

This report contains an analysis of past midair collisions and a summary of cockpit visual cutoff angles of some present-day aircraft. The collision information was obtained from 50 accident reports which were selected from 92 midair collision investigations covering a period from 1949 through 1954 Selections of the midair collision reports were based on one primary factor, namely, that a relative convergence angle was determined for the aircraft involved Analysis of the selected reports shows the angles at which the aircraft collided, the altitudes at which the collisions occurred, and the proximity of the accidents to airports

A summary of cockpit visual cutoff angles is given in conjunction with the collision analysis. This summary, showing averages of horizontal and vertical visibility cutoff angles for various air carrier, private, and military aircraft, supports the findings of the collision report analysis, namely, that

1. The overtaking of one aircraft by another has occurred in the majority of midair collisions.
2 Most aircraft have poor, to no, visibility in the rear hemisphere and seriously limited upward and downward vision in the forward area
3 Most midair collisions occurred within 5 miles of an airport and more than 50 per cent occurred within 1 mile.
4 More collisions occurred at an altitude of 500 feet or below than at all other altitudes
5. Many of the collisions analyzed involved convergence angles that placed one or both approaching aircraft beyond the cockpit vision limits of the other aircraft such that it was impossible for the pilot to see the approaching aircraft.

INTRODUCTION

Prior to World War II, little thought was devoted to the possible saturation of the airspace. However, the situation now is completely reversed and the aviation industry is cognizant of the problems arising with increased air traffic Realizing the magnitude of the midair collision problem and the urgency for a solution, the Technical Development Center of the Civil Aeronautics Administration at Indianapolis started investigating the various factors related to midair collisions as early as 1948.[1,2,3,4,5]

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*Manuscript submitted for publication September 1957.

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

[2]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.

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

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

[5]Wayne D Howell, "Determination of Daytime Conspicuity of Transport Aircraft," CAA Technical Development Report No. 304, April 1957.

COMMENTS AND CONCLUSIONS CONCERNING FLIGHT PATH DATA

1. THE MAGNETIC BEARING FROM END OF RUNWAY 13 TO THE OUTER MARKER OF ILS IS 131 THE ILS GLIDE PATH HEADING IS 128 MAGNETIC ASSUMING A TRACK OF 131 MADE BY NO 2 AIRPLANE FROM A POINT NEAR THE OUTER MARKER AND THE NO 1 AIRPLANE COURSE SAME AS ILS 126 THERE EXIST 5 CONVERGING TRACKS FROM THIS SITUATION NO 2 AIRPLANE MUST TURN LEFT 5 TO BE IN LINE WITH RUNWAY 13
2. THE ESTIMATED ANGLES GIVEN BY A PASSENGER ARE AT WIDE VARIANCE TO COMPUTED TIME SPEED AND DISTANCE OF FLIGHT PATHS
3. THE NO 1 AIRPLANE WAS WITHIN VISIBILITY LIMITS OF THE NO 2 AIRPLANE UP TO BUT NOT AFTER 3 MIN BEFORE COLLISION
4. THE NO 1 WINDSHIELD LIMITS WERE SUCH THAT THEY DID NOT OBSCURE THE NO 2 FROM THE VIEW OF THE *PILOTS POSITION AT ANY TIME EXCEPT WHEN POST OBSCURED VIEW BETWEEN POINTS 11 & 12 AND POINTS 19 & 20*
5. THE NO 1 WINDSHIELD LIMITS PERMITTED THE CO-PILOT TO SEE NO 2 FROM POINTS 10-19 ONLY
6. IF NO 2 HAD BEEN ON A HEADING OF 128 5 (SOLID LINE) INSTEAD OF THE ASSUMED 131 (DASHED LINE) IT WOULD HAVE BEEN IMPOSSIBLE DUE TO POST OBSTRUCTION FOR THE PILOT IN THE NO 1 TO HAVE SEEN NO 2 FROM THE OUTER MARKER (POINT 24) TO THE COLLISION POINT

TIME POINTS	SECONDS BEFORE COLLISION	VISIBILITY ANGLE NEEDED FROM		VISIBILITY ANGLE NEEDED DOWN NO. 1 / UP NO 2	ALTITUDE BETWEEN AIRCRAFT	DISTANCE BETWEEN AIRCRAFT	EYE STIMULUS ANGLE		EYE STIMULUS ANGLE TOWER TO	
		NO 1	NO. 2				NO. 1	NO. 2	NO 1	NO. 2
1	320	27 00 L	92 50 R	1 48	1117 FT	42 900 FT				
2	310	26 50° L	92 75 R	1 58	1117 FT	40 500 FT.				
3	300	26 00 L	93.50 R	1.68	1117 FT	38 100 FT.				
4	290	25 50 L	93 75 R	1 78	1117 FT	35,625 FT				
5	280	25 00° L	94.50 R	1 93	1117 FT	33 150 FT				
6	270	24.25 L	95.50 R	2 08	1117 FT	30 750 FT				
7	260	23 00 L	96.00 R	2 25	1117 FT	28 350 FT				
8	250	22 25 L	97 50 R	2 46	1117 FT	25 950 FT.				
9	240	20 75 L	98 50 R	2 72	1117 FT	23 550 FT			1 0233 IN AT A POINT 12 IN FROM EYES.	
10	230	19 00 L	100.25 R	3.03	1117 FT	21 225 FT				
11	220	17 00° L	102.50 R	3.38°	1117 FT	18 900 FT				
12	210	14 50 L	105.00 R	3.65	1117 FT	16 575 FT				
13	200	11 00 L	108.50 R	4 43	1117 FT	14 400 FT				
14	190	6 25 L	113 00 R	5 06	1117 FT	12 600 FT				
15	180	0 50 L	119 50 R	5 86	1117 FT	10,875 FT				
16	170	8 50 R	127 00 R	6 63	1117 FT	9 600 FT				
17	160	8 25 R	137.25 R	7 56	1116 FT	8 400 FT				
18	150	1 00° R	146.00 R	8 01	1,039 FT	7 380 FT				
19	140	1 50 L	152.50 R	8 33	963 FT	6 570 FT				
20	130	19 50° L	155 25 R	8.50°	886 FT	5 925 FT	1 10	0 26		
21	120	19 50 L	155 25 R	8 71	809 FT	5 280 FT	1 23	0 30		
22	110	19 50° L	155 25 R	8 95	732 FT	4 650 FT	1 43	0 33		
23	100	21 25 L	154 00 R	9 48	655 FT	3 975 FT	1 66	0 40	0 233	0 066
24	90	22 00 L	153.00 R	9 50°	585 FT	3 510 FT	1 93	0 46	0 266	0 066
25	80	22 00 L	153.00 R	9.50	520 FT	3 150 FT	2 10°	0 53	0 300	0.066
26	70	22 00 L	153 00 R	9 50°	455 FT	2 700 FT	2 46	0 60	0 333	0 066
27	60	22 00° L	153.00 R	9 50°	390 FT	2 280 FT	2 90	0 70	0.366	0 100°
28	50	22 00 L	153.00 R	9 50	325 FT	1 950 FT	3 24	0 83°	0 400°	0 100°
29	40	22 00 L	153.00 R	9 50	260 FT	1 560 FT	3 86	1 03°	0 433	0 133
30	30	22 00 L	153 00 R	9 50°	195 FT	1 170 FT	5 66	1 36	0 500	0 133
31	20	22 00° L	153 00 R	9 50	130 FT	810 FT	8 20	1 96	0 600	0 166
32	10	22 00 L	153.00 R	9 50°	65 FT	390 FT.	16 93°	4 10	0 700	0 166
						COLLISION POINT			0 900°	0 200

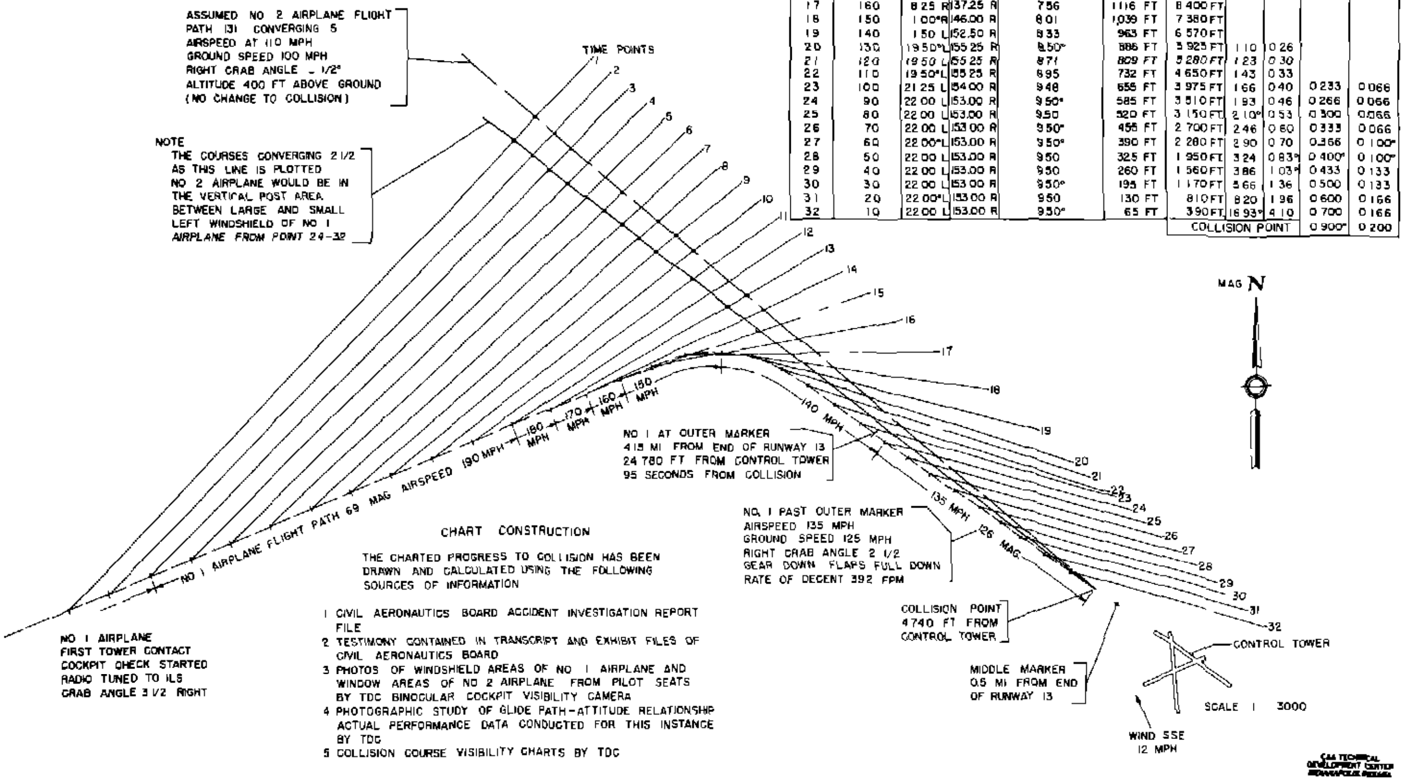

CHART CONSTRUCTION

THE CHARTED PROGRESS TO COLLISION HAS BEEN DRAWN AND CALCULATED USING THE FOLLOWING SOURCES OF INFORMATION

1. CIVIL AERONAUTICS BOARD ACCIDENT INVESTIGATION REPORT FILE
2. TESTIMONY CONTAINED IN TRANSCRIPT AND EXHIBIT FILES OF CIVIL AERONAUTICS BOARD
3. PHOTOS OF WINDSHIELD AREAS OF NO 1 AIRPLANE AND WINDOW AREAS OF NO 2 AIRPLANE FROM PILOT SEATS BY TDC BINOCULAR COCKPIT VISIBILITY CAMERA
4. PHOTOGRAPHIC STUDY OF GLIDE PATH-ATTITUDE RELATIONSHIP ACTUAL PERFORMANCE DATA CONDUCTED FOR THIS INSTANCE BY TDC
5. COLLISION COURSE VISIBILITY CHARTS BY TDC

Fig 1 Typical CAA Collision Analysis Chart

As additional background and a guide for future anti-collision research, an investigation of past midair accidents and related parameters, presented in this report, was made to determine some of the conditions and circumstances existing at the time of midair collisions

ANALYSIS OF MIDAIR ACCIDENT REPORTS

Procedure

An analysis was made of data contained in 50 midair accident reports and collision analysis charts selected from accident investigations during the period from 1949 to 1954 These included Civil Aeronautics Board Accident Investigation Reports, a report prepared by the Bureau of Safety Investigation of the Civil Aeronautics Board[6], and CAA Technical Development Center (TDC) collision analysis charts Figure 1 is a typical collision analysis chart which shows the visibility angles required for the pilots of each aircraft to see the other aircraft at 32 stations along each flight path The stations represent the positions occupied by each aircraft at every 10 seconds of elapsed time prior to collision

The primary consideration of the investigation covered by this report was the relative angle of convergence of flight paths between aircraft on collision courses Fifty reports were chosen in which the angle of convergence, either prior to or at the point of collision, was determined during the investigation of the accident Following the initial selection of the accidents to be studied, the reports and charts were carefully scrutinized for the existence of possible contributing factors to the collisions, including weather, visibility, altitude, and proximity to an airport

The horizontal plane was divided into 30° sectors to simplify the grouping of angles of convergence In only a few cases could the headings of the colliding aircraft be verified by surviving pilots In the majority of the collisions, the headings were approximations derived from testimony by witnesses, such as tower operators, airport employees, and bystanders, and also from flight plans, traffic patterns, recorded air-to-ground communications, and by inspection of the aircraft involved Thus, it is possible that flight paths were recorded with heading deviations as much as plus or minus 15° within a given 30° sector

Discussion

The accident reports first were analyzed to determine the angle of convergence that was the most predominant A summary of separation angles indicates that the greatest danger of midair collisions between two aircraft does not involve the head-on situation but shows, rather, that the overtaking situation predominates See Fig 2 Dividing the spherical space about an aircraft into forward and rearward hemispheres, and designating the forward convergence angles as head-on and the rearward angles as overtaking, about 80 per cent of the accidents then can be classified as overtaking accidents All of the accidents in this analysis occurred under visual flight rule (VFR) conditions Only one of the 50 accidents occurred in minimum VFR conditions, and 92 per cent occurred in ceiling and visibility unlimited (CAVU) weather

The aircraft operations involved in the accidents of this study are classified as private, air carrier, and military The military aircraft are only those involved with private and commercial aircraft in midair collisions Collisions involving military aircraft only are not included in this report The total number of each type involved is shown in Fig 3. The greater number of private aircraft involved in midair collisions may be partially explained by differences in the number of each group in existence. There were approximately 40 times as many private aircraft in existence than air carrier type aircraft In December 1955, there were 60,000 active private aircraft, 1,500 air carrier aircraft, and 40,000 military aircraft in existence

The distance relationship of the accidents with respect to airports is noteworthy because of its similarity to surface transportation The airport is to air travel what the city is to surface travel, that is, the focal point of converging traffic from all directions The proximity relationship, Fig 4, shows the percentage of accidents by distance from the airport It will be noted that 90 per cent of the midair collisions occurred within 5 miles of an airport and that 25 per cent of the midair collisions occurred over or within the boundary limits of an airport It also will be noted that 54 per cent of the midair collisions in this

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

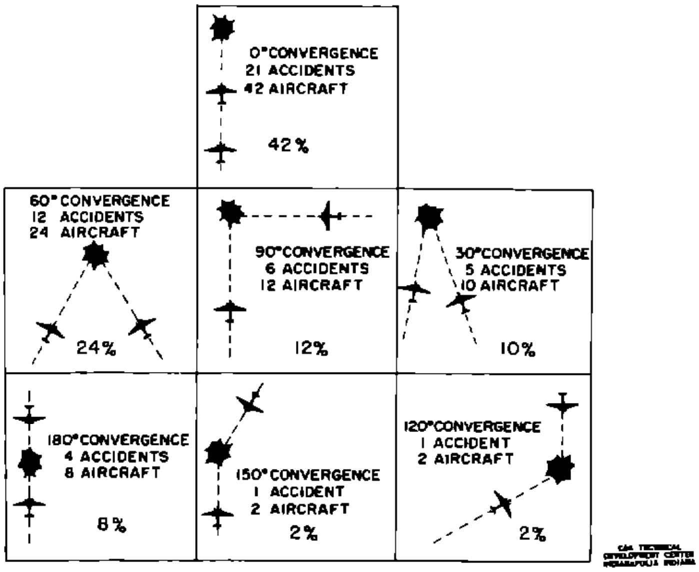

Fig. 2 Summary of 50 Midair Accident Investigation Reports for Years 1949 Through 1954

analysis occurred within 1 mile of an airport With this in view, it is conceivable that over 50 per cent of the midair collisions might be prevented through use of an anti-collision means having effectiveness over a relatively short range

The altitude above terrain at which 42 of the 50 collisions occurred is shown in Fig 5. Eight of the 50 accidents happened at altitudes undetermined by the accident investigation Figure 5 reveals that 23 accidents, or 55 per cent of those whose altitudes were known, occurred at 500 feet or below The bar chart shows that two collisions occurred above 3000 feet These were more than five miles from an airport

Figure 6 shows the altitudes for 26 of the 27 accidents that occurred within 1 mile of an airport Twenty-one collisions of the 27 were at an altitude between 5 and 500 feet One of the collisions within one mile of an airport was at an undetermined altitude

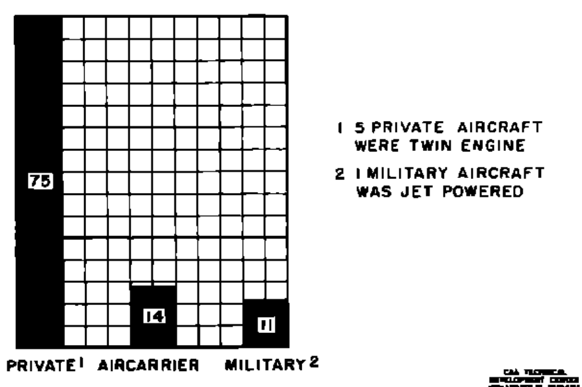

Fig 3 Summary of Aircraft Involved in 50 Midair Accident Reports

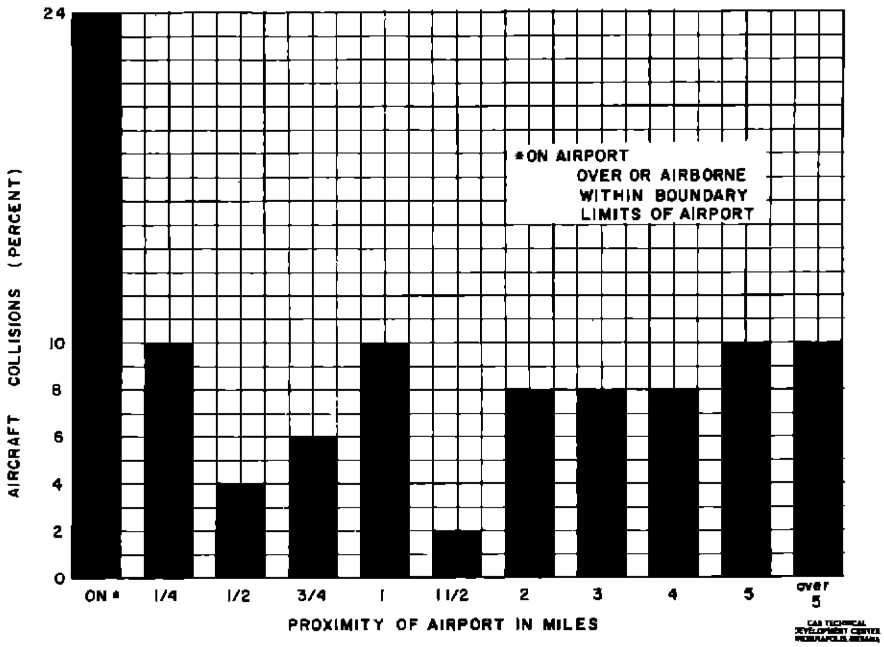

Fig 4 Summary of 50 Midair Accidents' Distance Relationship (1949 Through 1954)

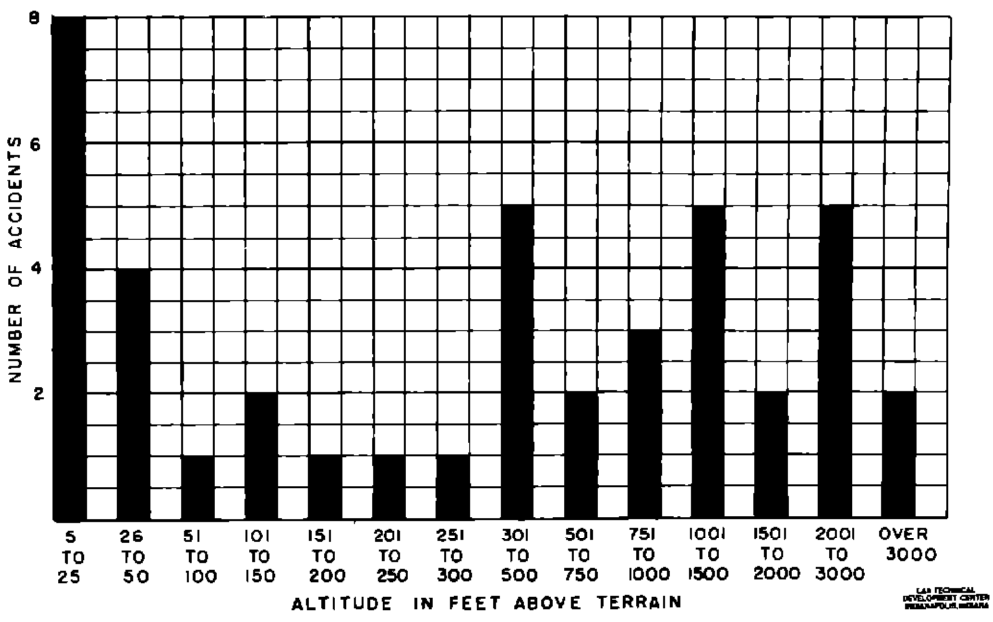

Fig 5 Number of Accidents and Altitudes of 42 Midair Collisions (1949 Through 1954)

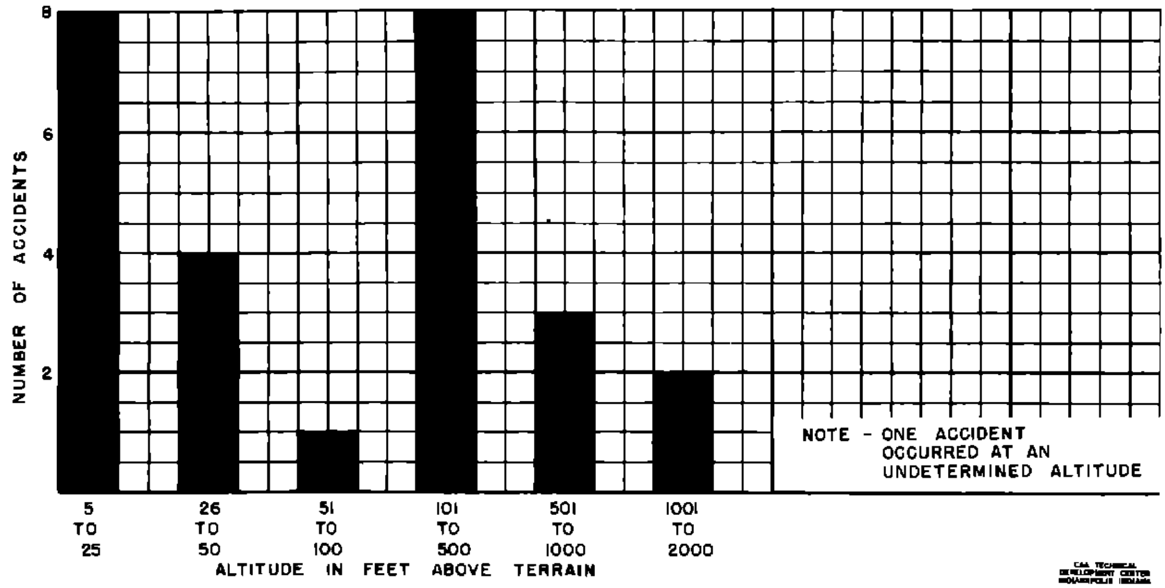

Fig 6 Altitudes at Which 54 Per Cent of the 50 Accidents Occurred That Were Within 1 Mile of an Airport

Fig 7 Binocular Cockpit Visibility Camera Set Up in a Single-Engine Aircraft

Fig 8 Binocular Cockpit Photograph of DC-7 One-Half Degree Nose Down Flight Attitude, Photographed from Pilot's Seat - Normal Eye Level 46 1/4 Inches Eye Level to Floor and 28 Inches to Windshield

SUMMARY OF AIRCRAFT COCKPIT VISUAL CUTOFF ANGLES

Procedure

A cockpit visibility study was carried out in connection with the midair collision analysis in an effort to determine whether or not there was any relation between past collisions and the usable and blind areas of aircraft cockpits A summary was made of the cockpit visibility cutoff angles for the three operational types of aircraft and an average vision cutoff angle was determined as well as the maximum and minimum angle

The camera used for this study is a binocular cockpit visibility camera [7] It has two lenses, the spacing of which is equal to the average distance between the human eyes The camera photographically records the outlines of the windows in aircraft cockpits as seen by the pilot It also superimposes a grid, composed of 5° increments, on the picture These increments then can be counted vertically and horizontally from the straight-ahead or reference center to give the total visibility and cutoff angles in degrees Figure 7 shows the camera installed in the pilot's seat of a small single-engine airplane, ready for photographing cockpit visibility

Discussion

Figures 8 and 9 are typical photographs which show the visibility from an air carrier and a private airplane cockpit, respectively The results of the cockpit visibility summary are shown graphically in Figs 10 and 11

The Lockheed Lodestar airplane has the greatest horizontal visibility for that type of aircraft, with 152° left horizontal cutoff and 102° right horizontal cutoff angles, for a total visibility arc of 254° The Temco Swift airplane displayed the best horizontal visibility of the six small single-engine-type aircraft studied, with a total horizontal arc of 288° of visibility from the pilot's seat. This is followed closely by the Ryan Navion and the Stinson Voyager airplanes

The forward vertical visibility cutoff angles for the three classes of aircraft are summarized in Fig. 11 The best above-the-horizon visibility of the 15 multiengine aircraft is in the Boeing 377, with 45° visibility, while the best below-the-horizon visibility is 16° in both the Martin 202 and the Douglas DC-3 airplanes In the single-engine class, the Stinson Voyager offers 45° above-the-horizon visibility while the Cessna 140 with 17° visibility has the best below-the-horizon visibility Figures 10 and 11 also show cutoff angles for some military aircraft Eleven military airplanes were involved in the accidents studied

It is readily apparent that civil aircraft have very limited visibility in the rear hemisphere, the area shown to be most vulnerable to collisions, and that visibility in the forward hemisphere is restricted, especially below the horizontal plane The vertical vision

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

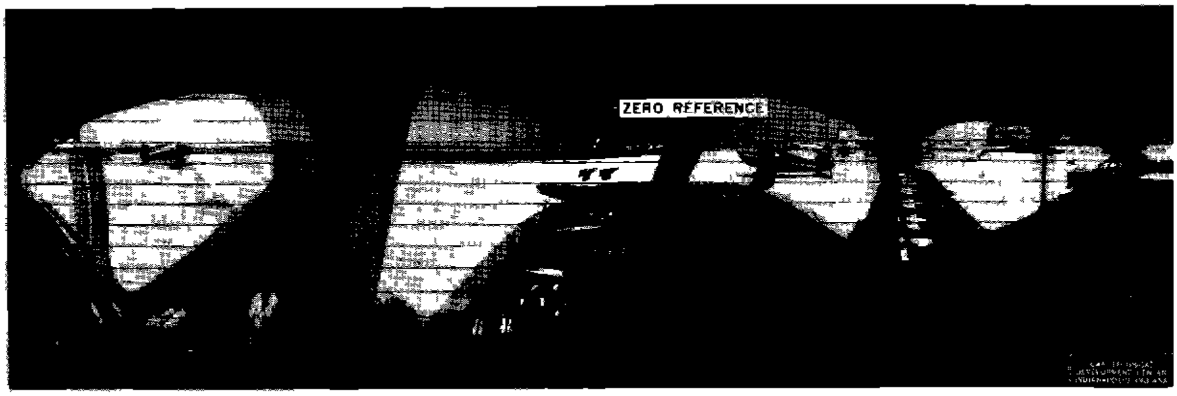

Fig 9 Binocular Cockpit Photograph of Navion Single-Engine Aircraft in Level Flight Attitude

restrictions emphasize the problems which now confront pilots when two aircraft are converging on climbing or descending flight paths These can involve flight path angles up to 45° with the horizon A typical situation is shown in Fig 12 Two air transports are involved One is on a level flight path The other is overtaking the first aircraft and is descending Neither pilot can see the other aircraft because of restricted visibility in the vertical plane

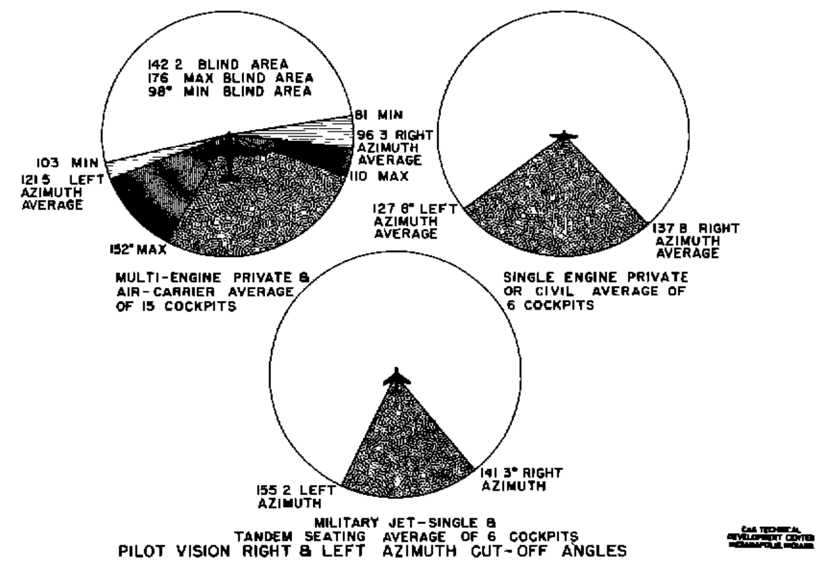

Fig 10 Pilot Vision Right and Left Azimuth Cutoff Angles

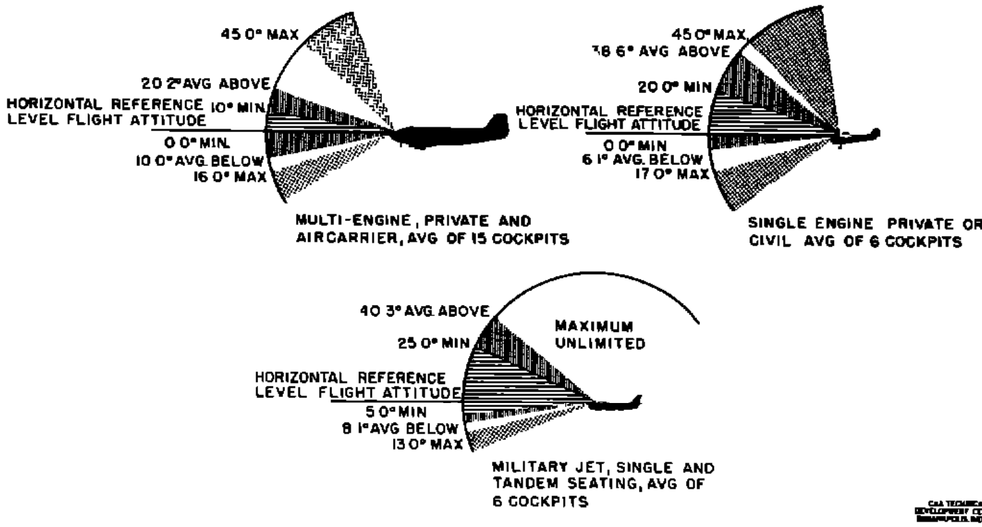

Fig 11 Pilot Vision Forward Vertical Cutoff Angles

CONCLUSIONS

1 It is evident that an overtaking situation was prevalent in most of the past midair collisions Forty-two per cent of the accidents in this study resulted from one aircraft directly overtaking another, and over 80 per cent of the accidents occurred when the horizontal angle between the converging flight paths was 90° or less

2 The rear hemisphere is restricted visually in the average civil aircraft

3 The majority of past midair collisions occurred within five miles of an airport Fifty-four per cent occurred within one mile of an airport

4 Midair collisions are most likely to occur at altitudes of 3000 feet or less above terrain Sixty-six per cent of the past midair collisions occurred at altitudes of 1000 feet or less

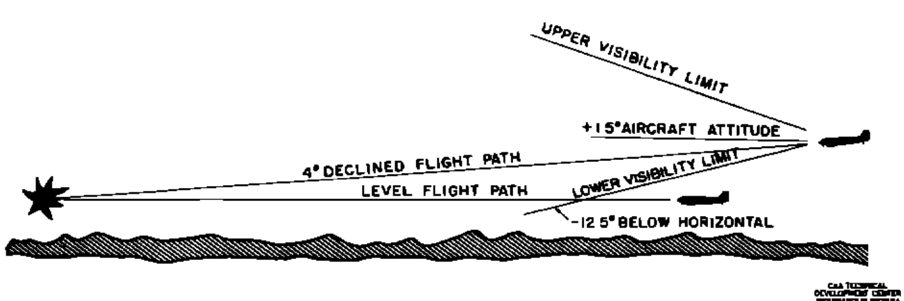

Fig 12 Typical Collision Condition Descending Flight Overtaking Straight and Level Flight