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REACTIONS OF PILOTS TO WARNING SYSTEMS FOR VISUAL COLLISION AVOIDANCE

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16. Abstract

A series of six experiments was conducted that have application to the development of Pilot Warning Instruments (PWI). The experiments were concerned with the effect of warning rates on pilot performance, pilot response to imminent collision threats, the evaluaion of scanning patterns, the value of warning-only, the effect of relative motion on pilot performance, and the effect of PWI display sector size. The results of these experiments offer a variety of useful data in the area of visual collision avoidance.

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INTRODUCTION

Purpose

The purpose of this report is to summarize a series of experiments that have application to the development of a Pilot Warning Instrument (PWI) from the pilot's standpoint.

Background

Midair collisions have always been recognized as a major aviation safety problem. A principal purpose of the Air Traffic Control (ATC) System is to provide adequate separation between aircraft operating under Instrument Flight Rules (IFR), or in controlled airspace, or otherwise under surveillance. Further, the organization of traffic in standard approach patterns and other structuring of routes contributes to the minimization of conflicts and potential near-misses. There remains, however, some residual possibility of midair collisions due to limitations of ATC surveillance, principally radar, heavy traffic at uncontrolled airfields on occasions, mixtures of IFR and Visual Flight Rules (VFR) traffic in locations with incomplete radar advisory service, and the possibility of traffic control errors.

VFR pilots follow the see-and-avoid rule, relying on visual search and detection, followed by avoidance maneuvers as necessary. IFR pilots are advised to practice vigilance as well, because of the chance that an aircraft not shown on radar or not being reported in the ATC system might conflict. This search can be effective because most IFR flight is conducted in weather that permits some visibility, and much of it is conducted in excellent visibility. It is recognized, however, that passing near or through clouds or flying in the presence of haze layers or other visibility-reducing conditions, makes unaided human vision an imperfect safety system.

To improve safety two techniques have been proposed. A Collision Avoidance System (CAS) and a PWI. A CAS is an airborne system which provides all the necessary functions to assure an output command indicating a collision avoidance maneuver with sufficient time to insure safe separation under all Visual Flight Rule (VFR) and/or Instrument Flight Rule (IFR) conditions. A PWI is a device intended to be utilized when VFR conditions prevail to assist the pilot in visually detecting other aircraft that may offer a potential threat of collision. After visual sighting, the pilot, utilizing PWI, must evaluate the situation and initiate any necessary evasive maneuver.

A CAS, which at this time is the most promising system, is based on the time frequency technique being developed under Air Transport Association (ATA) sponsorship. In time, this system may be installed in air carrier aircraft, but cost factors appear to rule out universal application of the ATA CAS. Presently developed PIW's appear to be cheaper; hence, they might find application in the large number of private and non-CAS-equipped general aviation aircraft. Present data are insufficient, however, to indicate the extent to which any PWI would enhance safety, and it is not clear what the value of various possible properties and characteristics of PWI's may be. Ideally we should like to be able to state what a PWI must be able to do, what its performance characteristics must be, to attain a particular level of safety assistance. This has been impossible due to lack of suitable simulation facilities to obtain key data to make such a model predictably powerful.

A contract with Rowland and Company (DOT FA69NA-357) with a major goal being the development of provisional PWI specifications has produced a model based on systematic analysis of the functions involved in visual detection.This effort highlighted significant gaps in present knowledge and contributed toward the design of the simulation experiments reported herein.

The first question put to test was, what is the effect of alarm rate; i.e., a PWI reporting targets when none was to be seen or a PWI failing to report some visible targets. Experimental analysis of this problem was urgent because most low-cost PWI proposals appear to have the defect of missing some possibly threatening targets and/or being sensitive to alarm from non-aircraft sources or from aircraft outside the pilot's visual range. It has been alledged that a PWI that gives false alarms would come to be disregarded, or alternatively that a too frequent alarming PWI would be ignored or turned off.

The second experiment focused on the immediate reaction and maneuver choice of a pilot confronted with a sudden and imminent collision threat. An answer to the question of what will the pilot do if he is given an alarm and then sees a very near threat was necessary to guide the development of avoidance rules of the road for use with a PWI.

The third question put to test was, how do alternative scanning patterns compare in effectiveness. Clearly a PWI should present warning information in a form that is compatible with the search capability of the pilot. It seemed possible that one or another scan geometry might be best and that this would give a clue as to the best PWI warning information.

Experiment four asked whether or not a warning-only PWI would reduce the percentage of targets that are missed when the targets were large and highly visible. Earlier studies had shown that targets so small or lacking in contrast that they were usually missed in unaided search were still missed most of the time when a PWI alarm was not supplemented with information as to where to look. More recent analysis had suggested that PWI applied more to close-in threats of the sort that usually would be seen in unaided search but that might be missed by a pilot preoccupied by in-cockpit duties.

The fifth simulation was directed to the question of the influence of the relative motion of an intruder aircraft on a pilot's ability to estimate the actual target movement, particularly whether or not the target constituted a collision threat. The aim was to discover how much time was required to observe the target and make a useful assessment of the situation. Obviously, this points to the PWI range specification.

Experiment six compared several possible cockpit displays with the goal of learning the best display sector size to support the eye orientation of the pilot seeking to detect. Since early studies of visual search behavior, it has been known that information that enables the searcher to look exactly where the target is to be found will facilitate detection. But how do you indicate to the pilot the exact direction in which he is to point his eyes? Practical instruments most likely have to be located on the panel and have to conform to standard module sizes. Given that limitation it is not at all clear that the best display is the most exact.

Together the six simulations studies were designed to fit the capabilities of the simulators on board and to contribute to filling in key gaps in our knowledge. Certainly there are additional pieces to the jigsaw puzzle that will have to be found and quantified before a model of PWI systems will be complete and can generate the predictions about safety that are needed. It is hoped, however, that the results of these experiments will fill some of the gaps and help to show the most fruitful next paths. This report covers the results of these six experiments.

DISCUSSION

Experiment 1 - Effect of Warning Rates of Pilot Performance

Purpose: The purpose of this experiment was to investigate the effect of varied alarm rates on pilot performance in detecting intruder aircraft.

Description: A group of 12 subject pilots was selected for this experiment. Six subjects had over 1,000 flight hours each and six subjects had under 500 flight hours. The subjects were thoroughly briefed on the purpose of the experiment. Each subject was familiarized with the Cessna/151 Visual Flight Simulator through a series of pretest flights with a qualified instructor pilot. During these flights, the subjects were also trained in all the procedures required to fly the prescribed flight plans.

The Cessna Cockpit Flight Simulator (Figure 1) was equipped with complete flight and engine instruments and dual VOR navigation equipment. All equipment was representative of general aviation aircraft equipped for IFR flight. The flight controls, instruments, and related equipment were driven by a modified analog computer from a Link Model-60 instrument trainer providing flight characteristics, control forces, and flight performance similar to a Cessna 182 aircraft without cockpit motion. The cockpit was located in a partial sphere having a 10-foot radius extending overhead and 120° on each side of the cockpit. The area to the rear of the cockpit was enclosed with black curtains to eliminate outside light from the dome area.

The target light projection system simulated a steady burning aviation red aircraft wing-tip light. The projected spot of light appeared as a point source approaching a visual angle of 1 minute of arc (0.035 inch) with an intensity of $.15 \times 10^{-5}$. This target level was chosen to be fairly difficult to locate and could be located in random search approximately 50 percent of the time. The projector lamp output was monitored by electromechanically inserting a photocell in the path of the projected light beam. Positioning of the target light within the dome was accomplished by use of a mirror remotely positioned in elevation and azimuth. A shutter and timers installed in the system allowed presentation of the light target of 30 seconds duration. A switch (button) installed on the control wheel was activated by the subject on target acquisition. Operation of the switch stopped the timer clock allowing readout of time to target acquisition in tenths of a second.

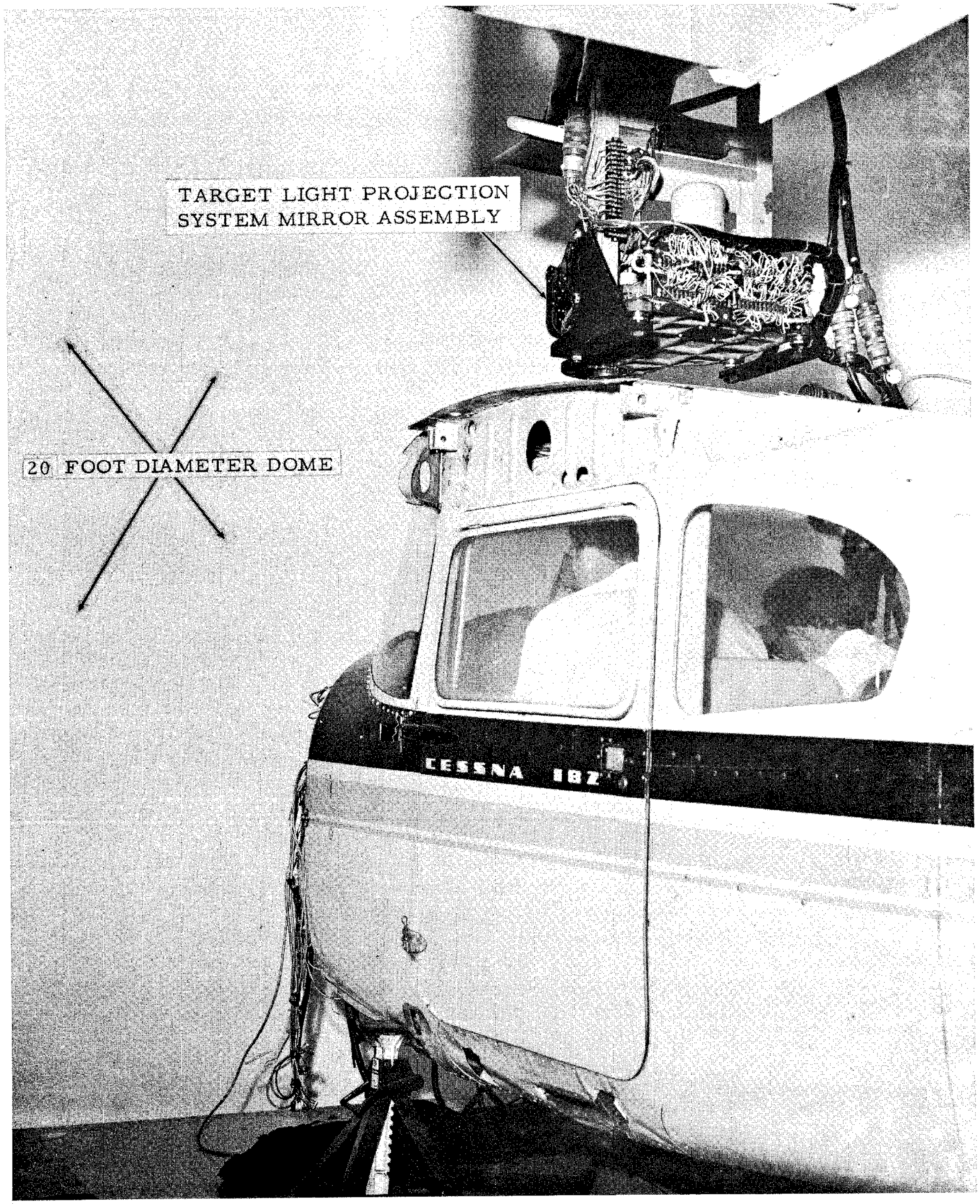

FIGURE 1 CESSNA COCKPIT FLIGHT SIMULATOR

Each subject was exposed to three experimental phases that were designed to test the subject's reaction to varied alarm rates. In Phase 1, 54 targets were presented during the course of the flight. The frequency of the target appearance was commensurate with the simulated flight plan traffic density. In this phase, the subject was given no warning of target presence. The subject was asked to press a button on the control wheel when he identified the target. Phase 1 was meant to simulate today's situation and is to be used as a baseline reference.

Phase 2 was similar to Phase 1, except an alarm in the form of a buzzer was used. There were twice as many alarms as targets. Phase 2 was meant to exaggerate the situation of an oversensitive PWI. In Phase 3, there were half as many alarms as targets thus simulating an undersensitive PWI. In both Phases 2 and 3 the same 54 targets were utilized as in Phase 1. Table 1 outlines the random order of the experimental phases and the flight plans.

Test Results: In Table 2, the column entitled "All Subjects" shows the total number of targets identified by each subject for the three experimental phases; 57.9 percent of the targets were identified overall, 49.4 percent in Phase 1, 66.5 percent in Phase 2, and 57.7 percent in Phase 3. Looking at the breakout of subjects by experience in Table 2, it is noted that the trends are similar, but the overall difference noted between Phases 2 and 3 was caused by the more experienced pilot group.

Table 3 summarizes the times required to identify the targets. For all subjects in Phase 1, the average time required was 11.8 seconds, in Phase 2 the time was 6.5 seconds, and in Phase 3 the time was 9.0 seconds. These times in association with the number of targets acquired indicate a definite improvement of performance in the experimental Phase 2 over the other phases. It was also noted that the less experienced pilots did better in Phase 3 than the more experienced group.

A three-way analysis of variance was conducted utilizing the time to detection scores. Table 4 shows the results of this analysis.

Data were also recorded on a sample portion of each flight on the time sharing (time spent looking out of windows versus time spent looking at instruments) utilized by each subject. Table 5 summarizes these data.

TABLE 1. - RANDOM ORDER OF EXPERIMENTS

Subject No.	Flight Hours	Experimental Order*		
I	< 500 hours	1A	2B	3B
II	< 500 hours	3B	1A	2B
III	< 500 hours	2A	3B	1A
IV	>1000 hours	1B	2A	3A
V	>1000 hours	3A	1B	2A
VI	>1000 hours	2B	3A	1B
VII	< 500 hours	3A	2A	1B
VIII	< 500 hours	1B	3A	2A
IX	< 500 hours	2B	1B	3A
X	>1000 hours	3B	2B	1A
XI	>1000 hours	1A	3B	2B
XII	>1000 hours	2A	1A	3B

* Number refers to experimental phase; letter refers to flight plans

TABLE 2. - NUMBER OF TARGETS DETECTED OUT OF A TOTAL OF 54

	All Subjects			Less Experienced Subjects			More Experienced Subjects		
Experimental Phases	1	2	3	1	2	3	1	2	3
Subject No.									
I	30	32	33	30	32	33			
II	22	37	36	22	37	36			
III	10	18	28	10	18	28			
IV	24	36	26				24	36	26
V	49	46	46				49	46	46
VI	16	25	27				16	25	27
VII	35	45	35	35	45	35			
V III	29	42	34	29	42	34			
IX	24	26	31	24	26	31			
X	33	42	13				33	42	13
XI	21	43	34				21	43	34
XII	27	39	31				27	39	31
	320	431	374	150	200	197	170	231	177
%	49.4	66.5	57.7	46.3	61.7	60.8	52.5	71.3	54.6
TOTAL %		57.9%			56.3%			59.5%	

TABLE 3. - REQUIRED AVERAGE TIME TO IDENTIFY THE TARGET

	All Subjects			Less Experienced Subjects			More Experienced Subjects		
Experimental Phases	1	2	3	1	2	3	1	2	3
Subject No.									
I	13.2	8.1	9.6	13.2	8.1	9.6			
II	16.2	6.7	9.8	16.2	6.7	9.8			
III	10.5	5.9	9.9	10.5	5.9	9.9			
IV	15.3	3.6	10.7				15.3	3.6	10.7
V	6.0	6.6	6.4				6.0	6.6	6.4
VI	8.7	7.4	8.8				8.7	7.4	8.8
VII	10.9	4.2	9.5	10.9	4.2	9.5			
VIII	11.9	7.9	6.3	11.9	7.9	6.3			
IX	13.3	6.3	8.1	13.3	6.3	8.1			
X	12.9	8.4	12.8				12.9	8.4	12.8
XI	12.5	5.4	8.6				12.5	5.4	8.6
XII	10.3	7.7	7.7				10.3	7.7	7.7
	141.7	78.2	108.2	76.0	39.1	53.2	65.7	39.1	55.0
Avg.	11.8	6.5	9.0	12.7	6.5	8.9	11.0	6.5	9.2

TABLE 4. - SUMMARY OF F TEST ON TIME TO DETECTION SCORES

Source of Variation	SS	df	MS	F Ratio
Subjects (A)	20774	11	1889	17.4*
Experiments (B)	13590	2	6795	62.6*
Conditions (C)	40857	53	771	7.1*
A x B	10441	22	475	Not Significant
B x C	21135	106	210	Not Significant
A x C	69202	583	119	Not Significant
A x B x C	103021	1166	88	Not Significant
TOTAL	279020	1943		

* Significant 1 percent level

TABLE 5. - PERCENTAGE OF TIME SPENT LOOKING OUT OF COCKPIT DURING INITIAL 30 MINUTES OF EACH FLIGHT

Subjects	Experimental Phase 1	2	3
I	34.8	27.8	*
II	10.7	16.2	*
III	10.3	18.5	16.5
IV	*	11.4	29.1
V	36.1	24.2	*
VI	16.8	18.6	35.2
VII	28.7	28.0	18.8
VIII	29.2	*	43.8
IX	27.0	19.0	43.6
X	39.8	38.6	26.7
XI	*	18.5	19.9
XII	25.3	22.5	23.4

Overall Average 25.3

*Data Missing

Experiment 2 - Pilot Response to Imminent Collision Threat

Purpose: The purpose of this experiment was to determine what a pilot's reaction would be to a sudden collision threat.

Description: A group of 12 subject pilots was selected. Seven had 500 hours of flight or less, and five had over 500 flight hours. The subjects were all briefed on the purpose of the project. The pilots were not given a flight task to perform in this experiment inasmuch as the trainer was not made operational.

The test equipment used was the National Aviation Facilities Experimental Center (NAFEC) Cherokee Cockpit Flight Simulator and a low-cost collision avoidance ground training projection system developed at NAFEC. The simulator was located in a partial sphere having a 10-foot radius extending 120° on each side of the cockpit. The projection system consisted of a 35 mm projector attached to a rotator to provide directional control. The target aircraft were 35 mm color slides of a Piper Cherokee-type airplane in nine different flight attitudes (Table 6). Three target placement positions were used on the viewing screen, 30° left, 0°, and 30° right, with each position having three altitude assignments, high (14°) on the horizon, and low (4°), for a total of nine dome positions. Four inanimate objects were also randomly presented to determine pilot response to a different target stimulus. Pilot control movement was recorded in the pitch and bank modes on a pen recorder.

The pilots flew two sessions, one session with a visible shadow horizon and one session without the horizon, to determine its influence on pilot judgment. Each of the 73 targets was presented for a period of 1 second, and the pilot was required to assess the relative positions of both aircraft, determine if the target aircraft posed a threat, and initiate evasive action by movement of the aileron, elevator, or both. If it was considered to be no threat, the pilot pressed a button on the yoke and no control movement was necessary.

Test Results: The data did not reveal any one evasive maneuver to be predominant. Initial evasive action was primarily directional and invariably a turnaway from the projected flight path of the intruder aircraft.

TABLE 6 .- TARGET REPLICATIONS

TARGET AIRCRAFT ATTITUDE	30^{o} LEFT			0^{o}			30^{o} RIGHT			TOTAL
	High	Horiz.	Low	High	Horiz.	Low	High	Horiz.	Low	
Climbing	24	24	24	X	24	24	24	24	24	192
Climbing Left Turn	24	24	24	24	24	X	X	24	24	168
Climbing Right Turn	12	24	X	12	24	24	24	24	24	168
Wings Level	24	24	24	24	24	24	24	24	24	216
Level Left Turn	24	24	24	24	24	24	24	24	24	216
Level Right Turn	24	X	24	24	24	24	24	24	12	180
Diving	24	24	24	24	24	X	24	24	24	192
Diving Left Turn	24	24	12	24	24	24	24	24	X	180
Diving Right Turn	24	24	X	24	24	24	24	24	24	192
Miscellaneous Targets					48					48
X - No Targets							Total Targets Presented			1752

Table 7 shows the number of evasive action responses by control movement for all targets. Individual response times ranged from 1.5 seconds to 5.0 seconds with the majority at about 2 to 3 seconds. A closing speed of 240 mph was assumed (120 mph each aircraft), and potential collision time was computed at about .56 second. Pilot response time per target averaged 2.34 seconds, precluding the possibility of the pilots to avoid head-on targets. Twenty-six percent of the targets were considered no threat by the pilots. Table 8 displays the no-threat responses for all target presentations, and is subdivided by target attitude, target azimuth, and target altitude for further comparison.

Pilot judgments were not significantly influenced by the presence or lack of the horizon. When asked what they considered the best rule to follow to avoid other aircraft, the pilots stated (1) turn away from the projected aircraft flight path, and if altitude separation is advisable, go down to attain faster separation, (2) keep the other aircraft in sight, and (3) use the "right-hand rule" where possible.

TABLE 7. - PILOT RESPONSE

HIGH TARGETS													
Target Azimuth	Aileron		Aileron and Elevator				Elevator		Aver. Resp. Time	No Threat	No Resp.	No Target
	Lt.	Rt.	Lt. Up	Lt. Dn.	Rt. Up	Rt. Dn.	Up	Dn.				
30° Left	4	67	0	5	7	26	1	9	2.35 s	60	25	
0°	24	35	4	20	6	20	5	18	2.39 s	34	13	2
30° Right	42	5	10	21	0	8	4	12	2.34 s	70	18	2

HORIZON TARGETS												
Target Azimuth	Aileron		Aileron and Elevator				Elevator		Aver. Resp. Time	No Threat	No Resp.	No Target
	Lt.	Rt.	Lt. Up	Lt. Dn.	Rt. Up	Rt. Dn.	Up	Dn.				
30° Left	5	51	2	5	17	23	9	19	2.21 s	53	9	
0°	27	36	13	22	17	16	21	29	2.35 s	29	54	
30° Right	58	3	13	33	0	0	9	17	2.33 s	72	11	

LOW TARGETS												
Target Azimuth	Aileron		Aileron and Elevator				Elevator		Aver. Resp. Time	No Threat	No Resp.	No Target
	Lt.	Rt.	Lt. Up	Lt. Dn.	Rt. Up	Rt. Dn.	Up	Dn.				
30° Left	0	54	1	2	18	21	3	3	2.40 s	48	7	
0°	24	17	11	14	12	7	17	2	2.32 s	30	33	1
30° Right	37	3	8	21	0	0	7	14	2.34 s	58	31	1

TABLE 8. - PILOT NO THREAT RESPONSE

Target Aircraft Attitude	30° LEFT						0°						30° RIGHT					
	Session						Session						Session					
	1			2			1			2			1			2		
	Hi	Hor	Lo	Hi	Hor	Lo	Hi	Hor	Lo	Hi	Hor	Lo	Hi	Hor	Lo	Hi	Hor	Lo
Level	3	2	2	0	2	1	2	0	1	0	1	2	0	2	2	4	2	3
Level Left Turn	1	2	3	1	2	1	2	1	1	2	0	1	3	1	1	4	3	3
Level Right Turn	2	0	3	4	0	2	2	1	0	2	0	0	5	1	2	3	1	0
Climb	6	4	3	9	3	3	0	0	2	0	0	1	7	2	2	10	6	5
Climbing Left Turn	9	5	4	11	3	4	9	0	0	7	1	0	0	2	0	0	2	0
Climbing Right Turn	0	1	0	9	1	0	8	0	0	0	1	0	7	5	7	12	5	6
Diving	0	2	8	0	2	5	0	0	0	0	0	0	1	7	6	1	3	4
Diving Left Turn	2	8	0	1	7	9	0	1	6	0	1	4	1	6	0	2	5	0
Diving Right Turn	2	5	0	0	4	0	0	3	8	0	2	4	6	11	7	4	8	10
Miscellaneous Target							0	8	0	0	9	0						

Session 1 - with horizon
Session 2 - without horizon

Total Number Threat Targets - 454

Experiment 3 - Effectiveness of Certain Simplified Scanning Patterns

Purpose: This experiment was concerned with the evaluation of the effectiveness of a variety of simplified scanning patterns as shown in Figure 2.

Description: A group of 12 subjects was selected. The subjects were carefully divided into two sets with six pilots in each. One set involved three professional pilots plus three additional high-time civilian pilots, and the other set involved less experienced pilots with less than 200 hours of total flight time.

The GAT II ground trainer, Figure 3, used was representative of a light, twin-engine aircraft similar to the Beech Baron in performance, and provided limited motion in the pitch and bank axis.

The trainer is situated in the center of a partial sphere of 10-foot radius, extending 240° in azimuth. The distance from the pilot's eye to the center of the dome was 10 feet. The luminance of the dome was homogeneous above the simulated horizon and had a luminance of .20 foot-Lambert. The horizon faded off to a luminance below the horizon of .16 foot-Lambert.

The red target image was quite small, subtending an angle of about 4 minutes from the pilot's eye, and had a brightness of $.3 \times 10^{-5}$ foot candle. This was meant to be a sub-foveal target that the pilot would have to search for long enough to establish his scan pattern.

Each subject flew five sessions in the trainer and, during the course of each session, 20 targets and five false alarms were presented for a period of 30 seconds.

Nine target positions were selected (Figure 4) and were randomized during presentation. The subjects were alerted to each target presentation by means of a buzzer and, upon detecting the target, the pilot activated a switch on the yoke which stopped the elapsed-time clock. Detection time was then recorded by the operator.

During the first session, the subject under a light workload was instructed to use his own method of scanning. During the four subsequent sessions, the subjects were instructed to use each of the four simplified scanning patterns. (Figure 2).

Scan Pattern II

Scan Pattern III

Scan Pattern IV

Scan Pattern V

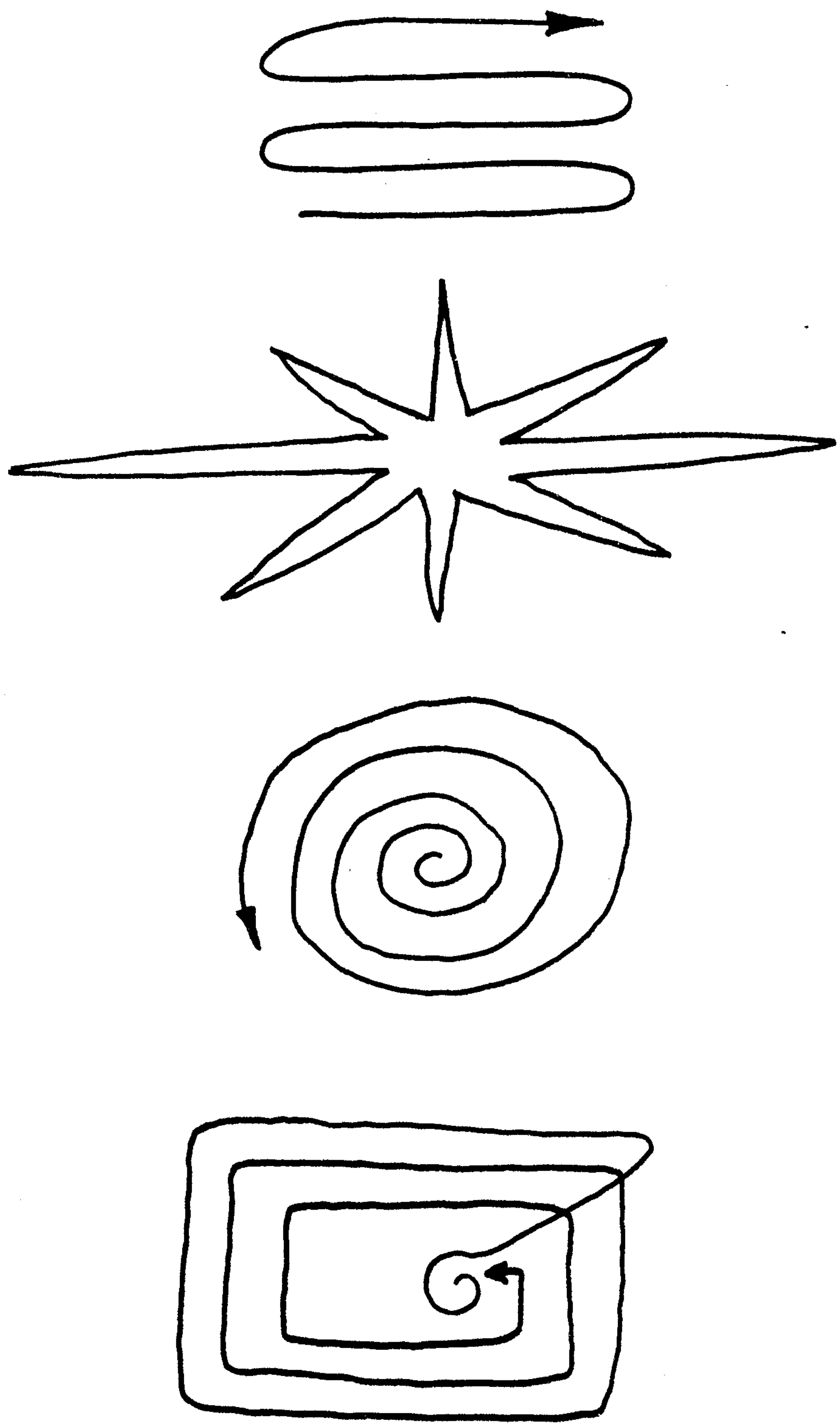

FIG. 2 SCANNING PATTERNS

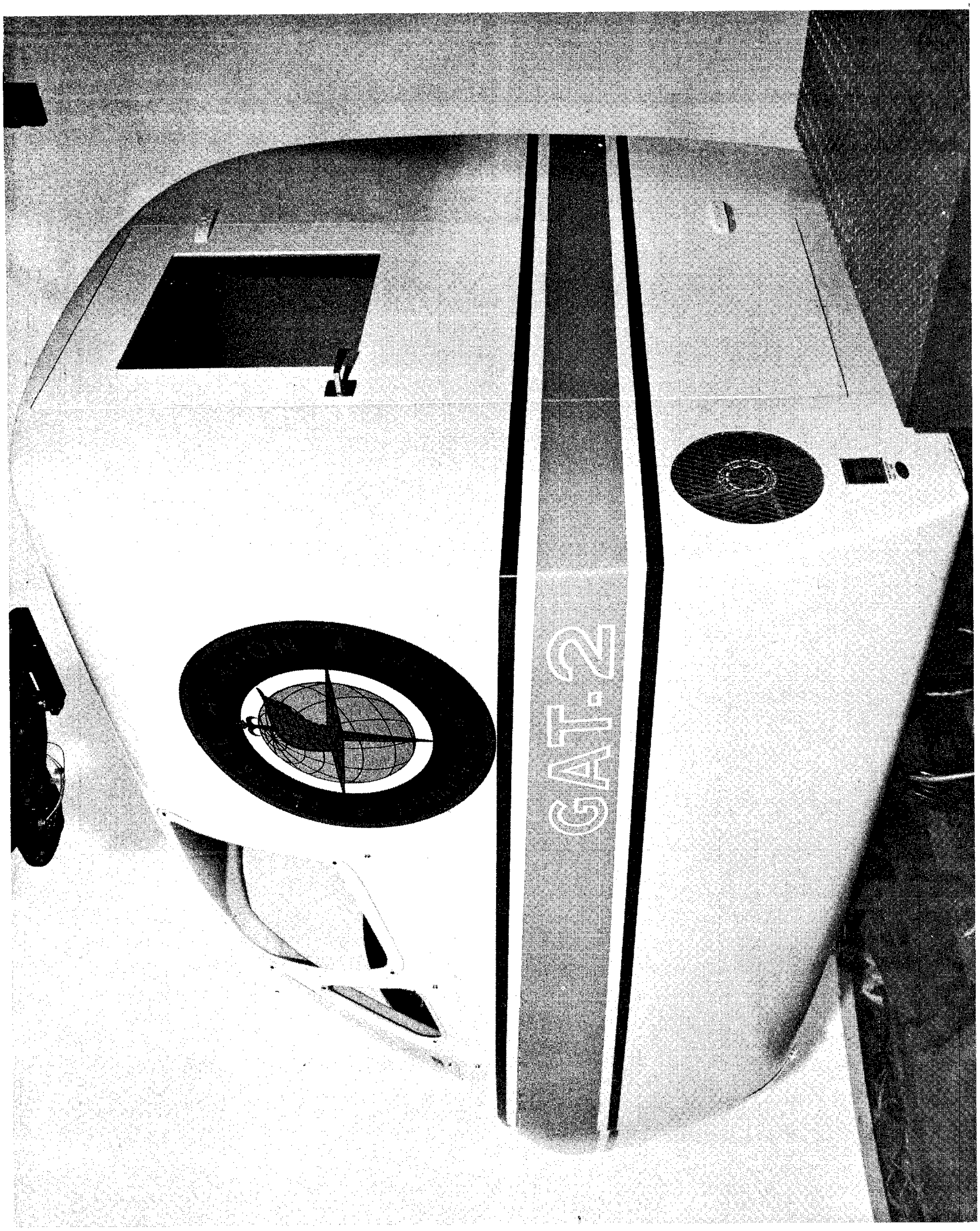

FIGURE 3 GENERAL AVIATION TRAINER 2 (GAT II)

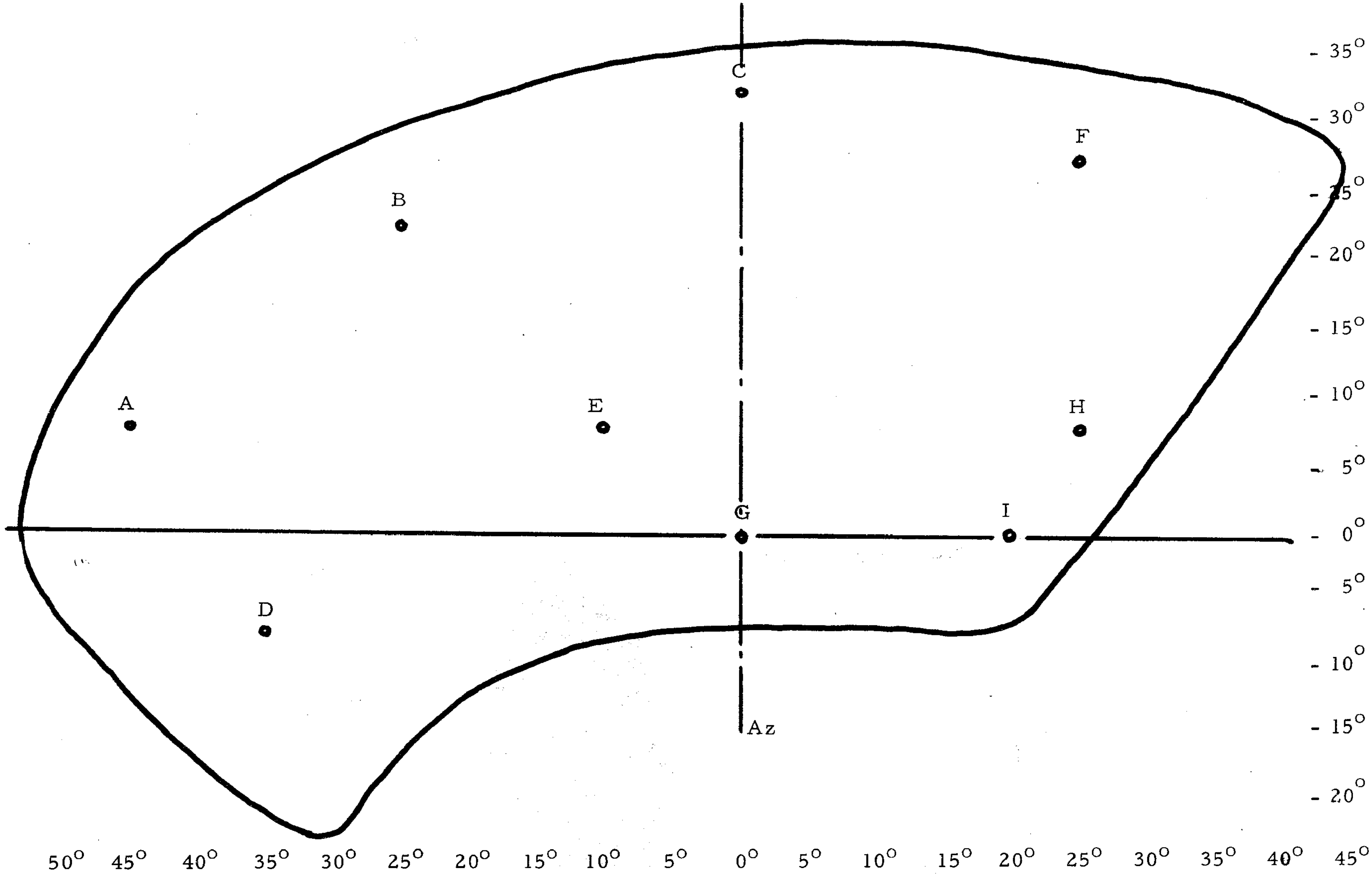

FIG. 4 TARGET POSITIONS - PILOT WINDSCREEN

Test Results: Table 9 shows that 1,200 targets were presented and 557 were detected for an average of 46.5 percent total detection. In addition, a greater number of targets (62 percent) were detected during session one where the subject used his own scanning method. A decrease in average detection scores then follows in the remaining four sessions with the lowest percent of detection occurring in session five (37 percent). Comparing the scores with target position (Figure 4) reveals that the highest detections occurred with those targets situated relatively close to the horizon and/or in the lower half of the pilot's windscreen. One might surmise that the shadow-horizon acted as a visual reference about which the search was more easily conducted. At the same time, this area ordinarily comprises the area of the greatest degree of collision threat and would, therefore, most likely receive more attention.

A rather wide variance in individual detection scores was noted, and ranged from a low of 20 percent to a high of 69 percent (Table 10) suggesting individual differences in eye accommodation, focus, etc. Eye focus tends to recede back toward the viewer after a short lapse of time as the eye fails to find a point to fix on. Under such circumstances, scanning becomes difficult and small targets may escape attention. This situation existed in this experiment; the target was small, the sky was homogeneous, and the shadow-horizon difficult to focus upon. Based on these situations, it took a long period of time to establish a scan pattern, thus causing the 15-second detection time.

Table 11 shows individual average detection times for each target and is based on the number of targets seen (557). For example, Subject #1 saw five "A" targets and averaged 11.6 seconds per target, etc. One might assume that the more experienced pilots having the higher number of flight hours might possibly have the better detection scores due to greater scanning experience, but such was not the case. Division of the high-time pilots from the low-timers shows that the combined average detection scores of the high-time pilots were less than those of low-time pilots, 44 percent against 48 percent.

Assuming a 10-second allowance for evasive maneuvering, the data show 113 target-detection times requiring more than 20.0 seconds. This projects itself to about 20 percent of the 557 targets detected as possible collisions, a somewhat significant amount.

TABLE 9

PROJECT 241-003-04X
INDIVIDUAL TARGET DETECTION SCORES
(ALL SESSIONS)

	T A R G E T										
Subject	A	B	C	D	E	F	G	H	I	False Targets	
1	5	4	2	8	14	6	10	5	10	25	
2	5	2	1	2	6	2	10	10	9	25	
3	2	0	2	1	5	3	9	4	7	25	
4	1	4	2	10	15	6	10	2	4	25	
5	0	4	1	1	4	5	5	7	4	25	
6	2	2	2	3	4	5	8	0	10	25	
7	3	1	5	5	15	4	10	8	8	25	
8	0	0	0	0	6	0	6	2	6	25	
9	3	7	3	6	17	6	9	5	7	25	
10	4	5	6	10	12	4	9	9	10	25	
11	5	5	3	8	15	5	10	3	7	25	
12	0	3	3	0	5	4	4	1	0	25	
Targets Presented	120	120	120	120	240	120	120	120	120	Total Targets	1200
Targets Detected	30	37	30	54	118	50	100	56	82	Targets Detected	557
% Detected	25%	31%	25%	45%	49.2%	41.5%	83%	46.5%	68%	Percent	46.5%

TABLE 10

PROJECT 241-003-04X
DETECTION SCORES BY SESSION (SCAN PATTERN)
PERCENT - ALL TARGETS

	Scan Pattern					
Subject	1	2	3	4	5	Average Percent (All Targets)
1	65%	55%	50%	80%	70%	64%
2	55%	60%	45%	35%	40%	47%
3	25%	55%	30%	30%	25%	33%
4	75%	50%	45%	55%	45%	54%
5	50%	45%	30%	20%	10%	31%
6	55%	40%	20%	40%	20%	35%
Average Detection	54%	52%	37%	43%	35%	44%
7	75%	80%	60%	45%	35%	59%
8	40%	0	30%	10%	20%	20%
9	85%	40%	60%	60%	70%	63%
10	90%	75%	50%	80%	55%	70%
11	75%	75%	55%	60%	40%	61%
12	55%	15%	15%	5%	10%	20%
Average Detection	70%	47%	45%	43%	39%	48%
Total Average Detection	62%	49%	41%	43%	37%	

NOTE:
Subjects 1-6 - High flight time pilots
Subjects 7-12 - Low flight time pilots

TABLE 11

PROJECT 241-003-04X
AVERAGE DETECTION TIME PER NUMBER OF TARGETS SEEN

T A R G E T

Subject	A		B		C		D		E		F		G		H		I				
1	5	11.6	4	14.3	2	6.1	8	9.7	14	12.5	6	14.6	10	5.0	5	16.5	10	10.0			
2	5	11.1	2	12.0	1	10.1	2	17.1	6	17.3	2	12.3	10	5.2	10	12.2	9	11.0			
3	2	6.4	0	0	2	25.2	1	17.3	5	24.5	3	12.0	9	10.7	4	16.5	7	14.7			
4	1	22.8	4	18.2	2	6.5	10	10.8	15	12.0	6	6.1	10	9.7	2	13.6	4	9.2			
5	0	0	4	13.4	1	16.0	1	14.4	4	12.9	5	22.0	5	3.1	7	15.1	4	10.2			
6	2	14.2	2	17.1	2	25.1	3	15.5	4	17.6	5	14.0	8	13.7	0	0	10	15.0			
7	3	20.7	1	26.3	5	21.9	5	8.2	15	12.8	4	24.5	10	7.7	8	18.2	8	11.0			
8	0	0	0	0	0	0	0	0	6	9.9	0	0	6	15.2	2	13.4	6	14.2			
9	3	17.1	7	15.8	3	21.6	6	14.4	17	11.2	6	17.8	9	11.7	5	13.6	7	11.5			
10	4	9.1	5	10.8	6	10.0	10	13.6	12	14.9	4	16.0	9	10.3	9	7.2	10	11.3			
11	5	8.0	5	11.8	3	12.6	8	17.4	15	13.1	5	18.6	10	10.8	3	19.8	7	15.5			
12	0	0	3	15.8	3	13.2	0	0	5	20.8	4	14.5	4	21.3	1	7.5	0	0			
Total Targets Detected	30		37		30		54		118		50		100		56		82		Overall Detection Time		
Average Detection Time		13.4		15.5		15.2		17.3		14.9		15.6		10.3		13.9		12.1	14.2		

Individual eye movements were recorded on 16 mm film on each subject during the first session to determine if a possbile correlation existed between the subject's normal scanning pattern, as might be indicated by his eye movement, and his scoring on any of the various scan patterns under test. No significant correlation was evident.

To answer the question of how effective one scan pattern is compared to another, the results indicate that the four scan patterns under test proved to be less effective in terms of the number of targets seen than the pilot's own individual method of scanning. Pilot opinion substantiates this conclusion by stating how "unnatural" the various test scan patterns felt to them, except the "horizontal sweep" which was, in effect, quite similar to their own scanning method. In summary, we find that:

1. Most pilots experienced some degree of difficulty adhering to the various scan patterns.

2. The "horizontal-sweep" scan pattern felt most natural; the "star" scan most unnatural.

3. Most pilots felt the "horizontal-sweep" scan was more effective and was the same or better than their own scan pattern.

4. Most pilots stated the "horizontal-sweep" scan was the one they most normally used.

5. Most pilots felt that teaching pilots to scan in a specific manner was advisable.

6. Most pilots felt that the sessions in the trainer did help them become aware of the inadequacy of their own scan technique.

Experiment 4 - Evaluation of Warning-Only

Purpose: The purpose of this experiment was to determine the value of a short-range, "warning-only" PWI as an aid to visual detection of aircraft.

Description: During the shakedown phase, employing the experimenters and simulator operators as pretest subjects, target brightness and sky/horizon brightness were adjusted to produce a light dusk condition to achieve about 75 percent detection of the targets when no PWI was used.

Each subject flew four sessions in the GAT II trainer consisting of two different routings of a short cross-country flight. Throughout each session, 40 head-on silhouettes of an aircraft having a 3-inch wing span were presented for 10 seconds each in the pilot's windscreen and were limited to 45° left and 45° right of center or dead-ahead as viewed by the pilot. During two of the sessions, a PWI warning accompanied the onset of the target projection. The remaining two sessions did not employ the use of the PWI warning. The sessions were randomized, as were the two cross-country routings. Targets varied in height from about 6° below the shadow-horizon to about 16° above the horizon.

Test Results: Of the 1,600 targets presented, 1,324 were detected; an overall score of 83 percent. From this result it is readily apparent that these were easy targets to see. Compared to the 1/10-inch-long images used at the same 10-foot viewing distance in the Sperry (Reference 1) search experiment, the present images were 3 inches in wingspan (a small aircraft at a range of 1,200 feet).

The target detection scores are summarized in Table 12. Inspection of that table reveals that the overall average of 83 percent is composed of widely different scores for sessions with PWI warnings versus sessions without warning, and that practice effect is clearly apparent with the second session under a given condition providing a marked improvement from the first session. This suggests that for pilots needing training, PWI is a good crutch.

Since the principal interest is in the effect of PWI warning, the data may be rearranged to provide two direct comparisons; score on the first session with and without PWI, and score on the second session with and without PWI. Averages for the 10 pilots prove to be 69 percent without warning versus 89.5 percent with warning for the first pair of sessions. This

TABLE 12. - TARGET DETECTION SCORES

Subject	Without PWI Warning						With PWI Warning					
	Session 1			Session 2			Session 1			Session 2		
	Yes	Late	No	Yes	Late	No	Yes	Late	No	Yes	Late	No
1	32	1	7	28	1	11	39	0	1	36	0	4
2	25	1	14	34	0	6	35	0	5	38	0	2
3	31	1	8	34	1	5	37	0	3	35	0	5
4	29	1	10	37	0	3	39	0	1	40	0	0
5	24	2	14	28	2	10	31	0	9	31	0	9
6	22	1	17	33	0	7	34	0	6	36	0	4
7	30	0	10	39	1	0	37	1	2	40	0	0
8	29	0	11	32	0	8	39	0	1	39	0	1
9	30	0	10	25	1	14	30	1	9	36	2	2
10	15	3	22	24	0	16	35	0	5	36	0	4
Total	277		123	320		80	358		42	369		31
Percent	69.2%			80.0%			89.5%			92.2%		
	74.6%						90.8%					

represents a reduction in the undetected targets from 31 percent to 10.5 percent, about a 3-to-1 reduction. Averages for the second session are 80 percent without warning and 92 percent with warning. This is a reduction in the undetected targets from 20 percent to 8 percent, considerably better than a 2-to-1 reduction.

The second major difference apparent in the Table 12 target detection scores is between subject pilots. On the first session without PWI warning, for example, scores ranged from 47 percent to 82 percent. On the first session with PWI warning, those same two pilot subjects scored 87 percent and 97 percent. Similar consistent differences are apparent throughout the table making it clear that some pilots score higher in target detection under this workload than do other pilots. The Sperry experiment had demonstrated that a passive observer could outscore a pilot under workload; so the question was asked, did the professional plot pilot subjects in this experiment outscore the pilots with more moderate experience levels. Table 13 summarizes those data.

TABLE 13. - PERCENT TARGET DETECTION BY PILOT CATEGORY

	Without PWI Warning (%)	With PWI Warning (%)	Total Average (%)
High-Time Pilots	81	95	88
Moderate-Time Pilots	68	86.5	77.2

The five professional pilots scored 81 percent without warning and 95 percent with the PWI. This is a reduction in residual threat from 19 percent of the targets to 5 percent, nearly a 4-to-1 reduction. The subject pilots with less flying experience, presumed to have been more burdened by the workload of flying the GAT II simulator, scored 68 percent without warning and 86.5 percent with PWI. This represents a reduction in residual threat from 32 percent to 14 percent, better than 2-to-1.

The third major trend apparent in the target detection scores presented in Table 12 is the practice effect. Comparing the first and second sessions without PWI warning for the 10 subject pilots yielded improved detection in eight of the 10 paired sessions. Similarly, for the pairs of sessions with

PWI warning, six subjects improved from the first to second sessions, two slipped back, and two did equally well. Hence, overall there were 14 improvements with practice versus two declines and four remaining even.

The major finding of this study is that a warning-only PWI does increase detection of highly visible targets by a pilot under workload. As shown in Table 12, a few detections were recorded after the target had disappeared. The vast majority came within the 10-second exposure period. This suggests that the average detection time was substantially less than 10 seconds. Two possible over-extensions of the results should be avoided. First, the designation "warning-only" does not mean that a PWI that performed the way the simulated PWI did in this experiment would be a simple or inexpensive device. In this experiment the alarm occurred only when there was a potentially visible target. Also, there were no targets without an alarm. Neither of these conditions would be simple to implement in a real system. Second, the experiment cannot be considered a test of effectiveness in collision avoidance. Since threat evaluation was not made and no maneuvers were selected, the data reflect the impact of a local area discrimination PWI on detection, not avoidance. Non threats were not filtered; most of the targets appearing 6° below the horizon and many of the targets in other positions in a real-world situation would be recognized to be non threats. The point of including them in this experiment was simply that intruders that go undetected are considered to constitute the population of aircraft that contains an occasional individual aircraft that is a threat. Calvert (Reference 2) has shown that correct classification of detected intruders is far from automatic. Still, it seems evident that when aircraft fly under the see-and-avoid rule, detection is the essential first step in air-derived separation assurance.

Experiment 5 - Effect of Relative Motion on Pilot Judgment

Purpose: The purpose of this experiment was to determine the influcence of the relative motion of an intruder aircraft on a pilot's ability to determine actual intruder flight paths.

Description: A group of 12 subjects was selected. They were divided into two groups of flight experience. The first group had flight times ranging between 300 and 2,500 hours and the second group had flight times ranging between 3,000 and 11,000 hours. All the subjects were given sufficient familiarization sessions in the GAT II Simulator prior to actual data collection.

A red flashing point source of light served as the target image which simulated an aircraft rotating beacon and was programmed for near misses and collision courses with varying degrees of relative motion. The flash rate of the light was 72 flashes per minute. The range used for target presentation varied from 1.5 miles to 6 miles and target brightness varied from a maximum of 1.3×10^{-5} foot-candle (1.5 miles) to $.019 \times 10^{-5}$ foot-candle (6 miles).

An experimental PWI instrument was constructed and installed in the GAT II instrument panel. The circular face of the instrument was divided into five sectors of 60° each covering 150° to the right and to the left of dead ahead.

Each of the 12 subjects flew one session in the GAT II trainer. Throughout each session 35 targets were presented. Targets 1 through 10 had three repetitions, and Targets 11 through 15 were displayed once. The pilot was required to maintain a constant heading (360°), altitude (2,000 feet), and airspeed (180 mph). This was necessary in order to greatly simplify programming the initial start position of the targets. During this experiment, the pilots were not given any additional workload other than maintaining heading, altitude, and airspeed. All targets were presented at the same altitude as the GAT II (2,000 feet).

Throughout each session, the pilot was alerted to each target presentation by means of a buzzer and the PWI display in which a particular sector lit up to denote the area of the target location. Upon detecting the target, the pilot pushed a button on the yoke of the simulator. This action simultaneously stopped the detection time recording clock and released the target to perform its programmed function. The pilot then verbally assessed the action of the target (relative motion) for its time duration of 60 seconds, and the experimenter in the cockpit translated the pilot's verbal assessments to the recorder by means of his control box.

Test Results: Inasmuch as the prime measurement of the data was pilot response to target relative motion versus time, the results of the experiment are largely shown in graphical form combining those two elements for easy comparison.

Figure 5 displays the individual target/GAT II geometry with associated angular velocity plots. Targets 1 through 10 were programmed as near misses while Targets 11 through 15 were programmed as collisions. The graphs shown in Figures 6 through 15 represent a more detailed descrption of the relative velocity between the GAT II and the target. The summary of the subject's correct decisions is plotted on each graph in the form of the mean and standard deviation (σ).

The subjects consistently made their first correct decisions sooner when the target appeared on the left as compared to an identical target which appeared on the right. The same was true for their final decision. In most of the courses, the first correct decision was converging with diverging decision after the target had passed.

The first measurement recorded was detection time. Table 14 shows average detection times for all targets. Each block displays the average time for individual target repetitions for each pilot subject. Average detection times are taken for subjects and targets.

Targets 1 through 10 were presented three times per session and Targets 11 through 15 were presented once. The average detection time for all targets is about 15 seconds, a rather high and difficult figure to explain. However, it was noted by the experimenter that on a great number of occasions, and despite numerous warning, the pilots ignored the PWI warning momentarily in order to assure positive control of the trainer before searching for the target.

Pilot responses regarding target action averaged about 80 percent correct, indicating a significant degree of accuracy in assessing the movement of the targets. Conversely,

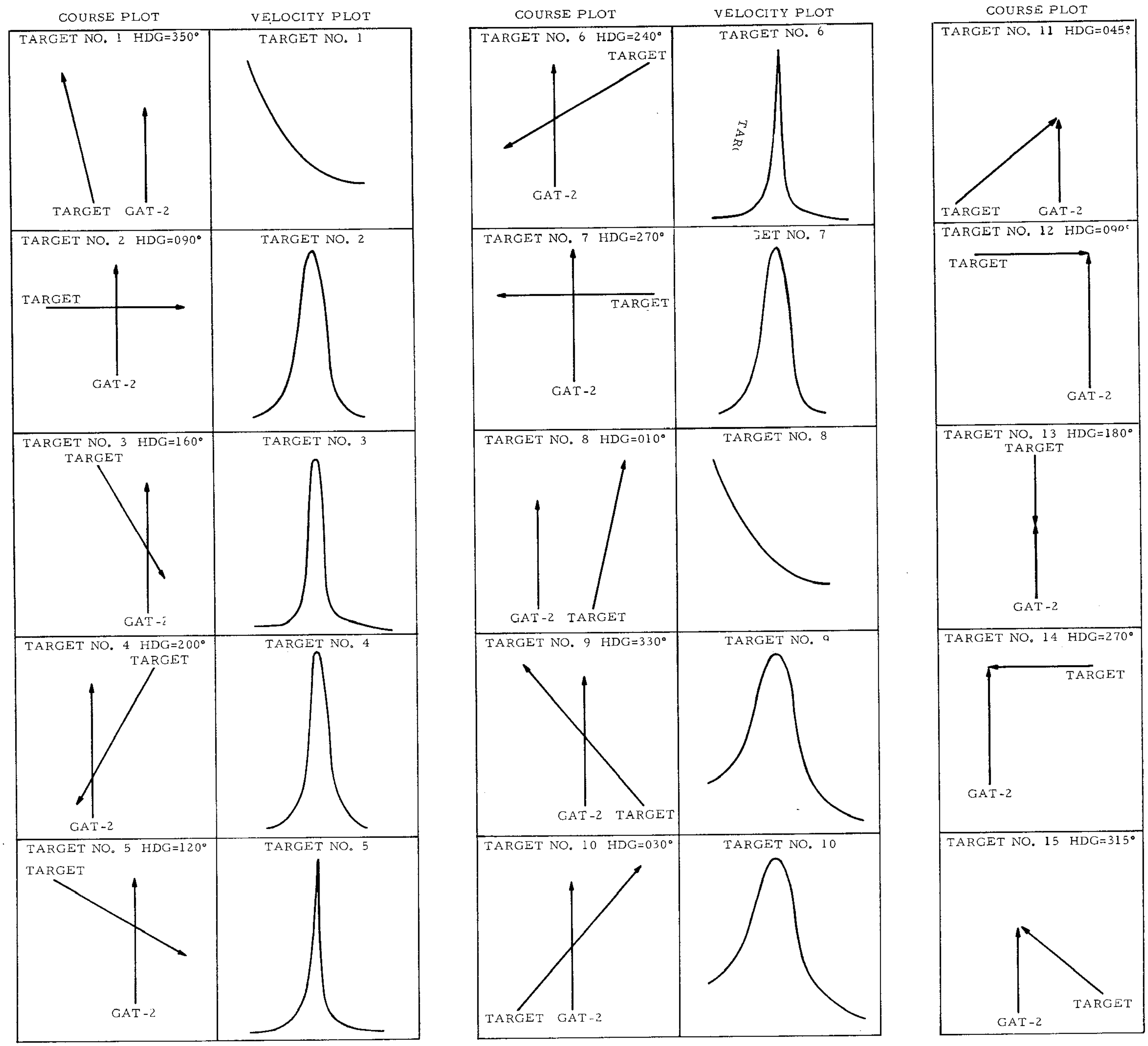

FIGURE 5 TARGET/GAT II COURSE GEOMETRY

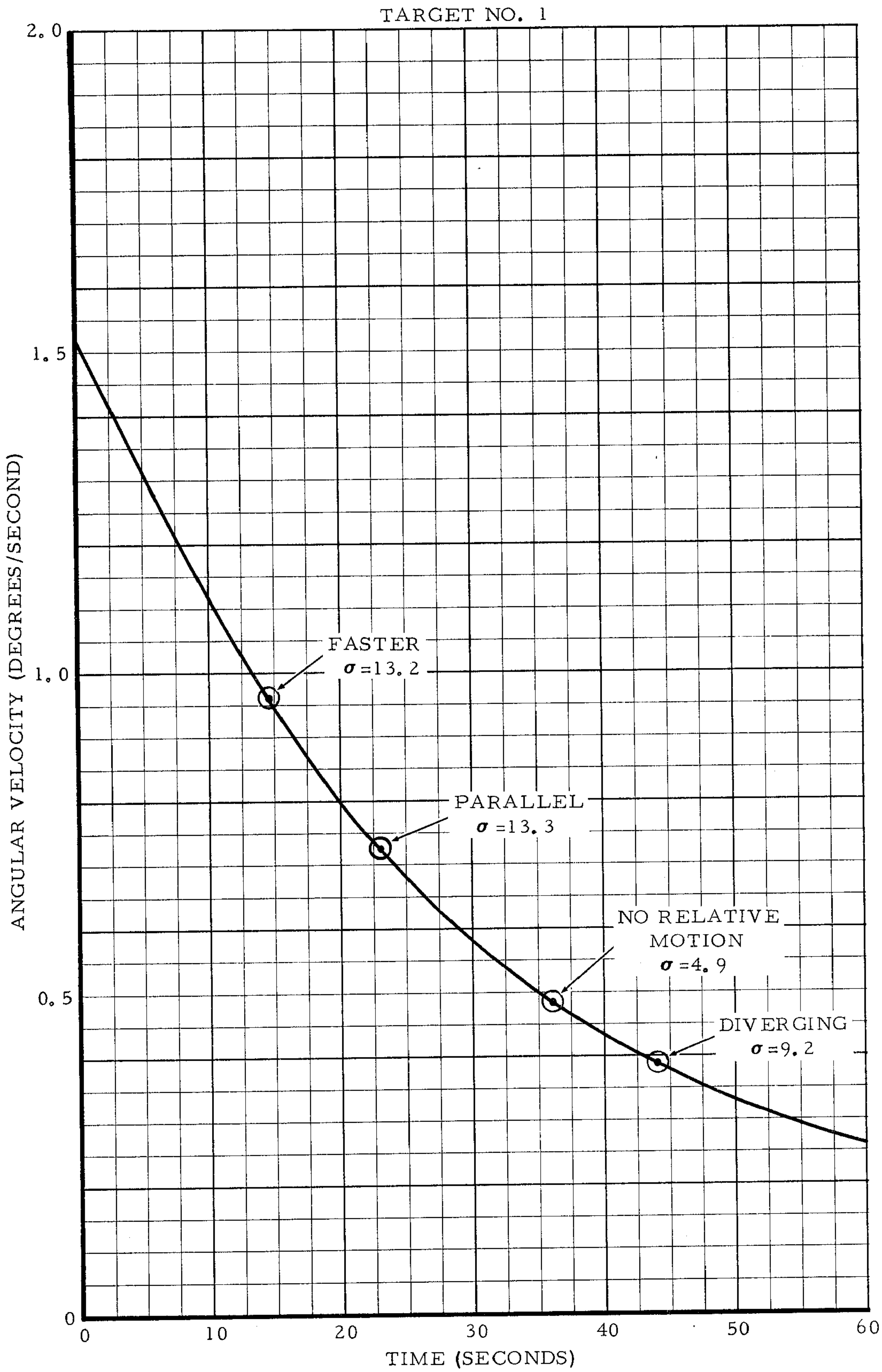

FIGURE 6 TARGET ANGULAR VELOCITY PLOT - TARGET 1

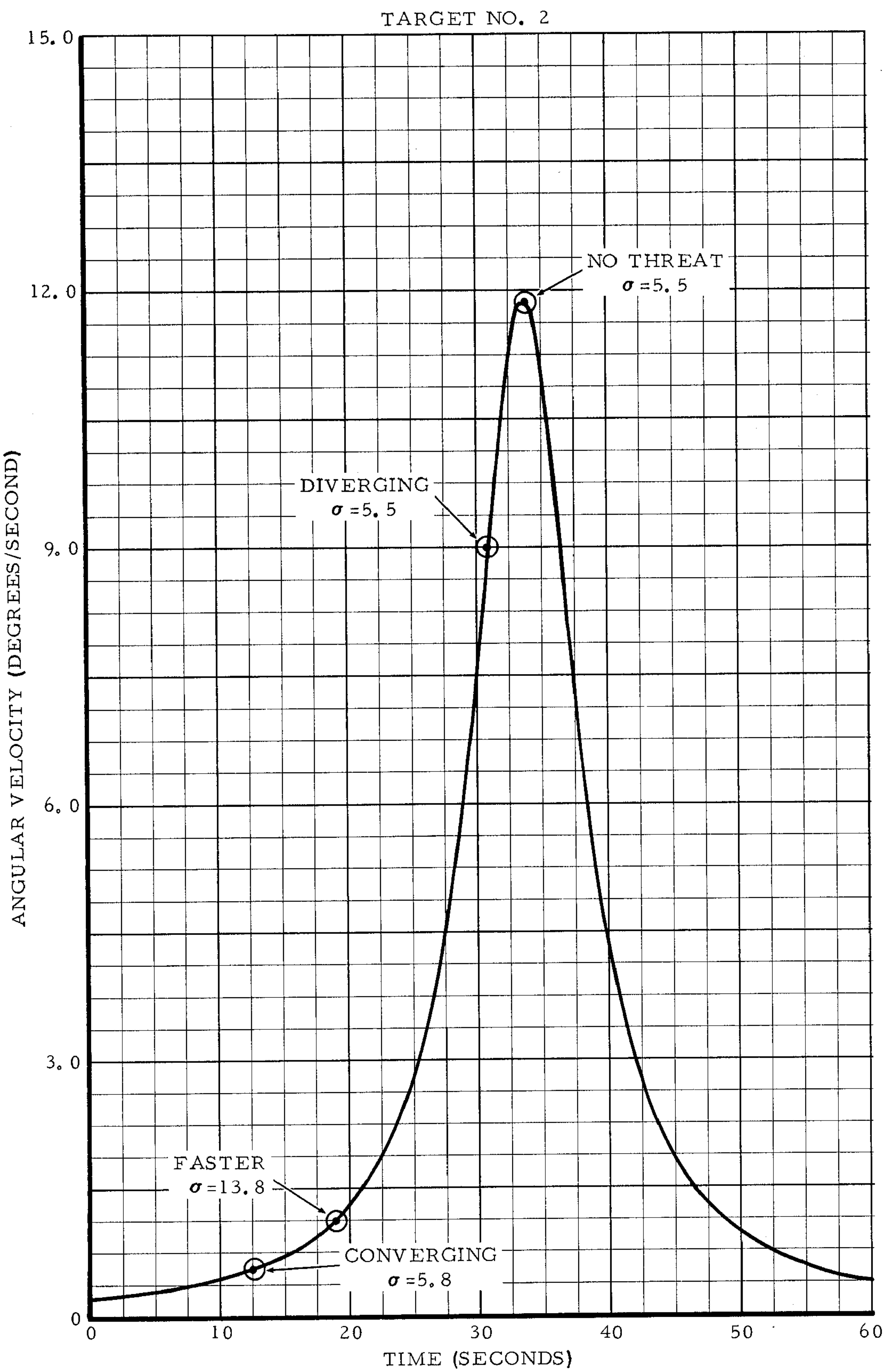

FIGURE 7 TARGET ANGULAR VELOCITY PLOT - TARGET 2

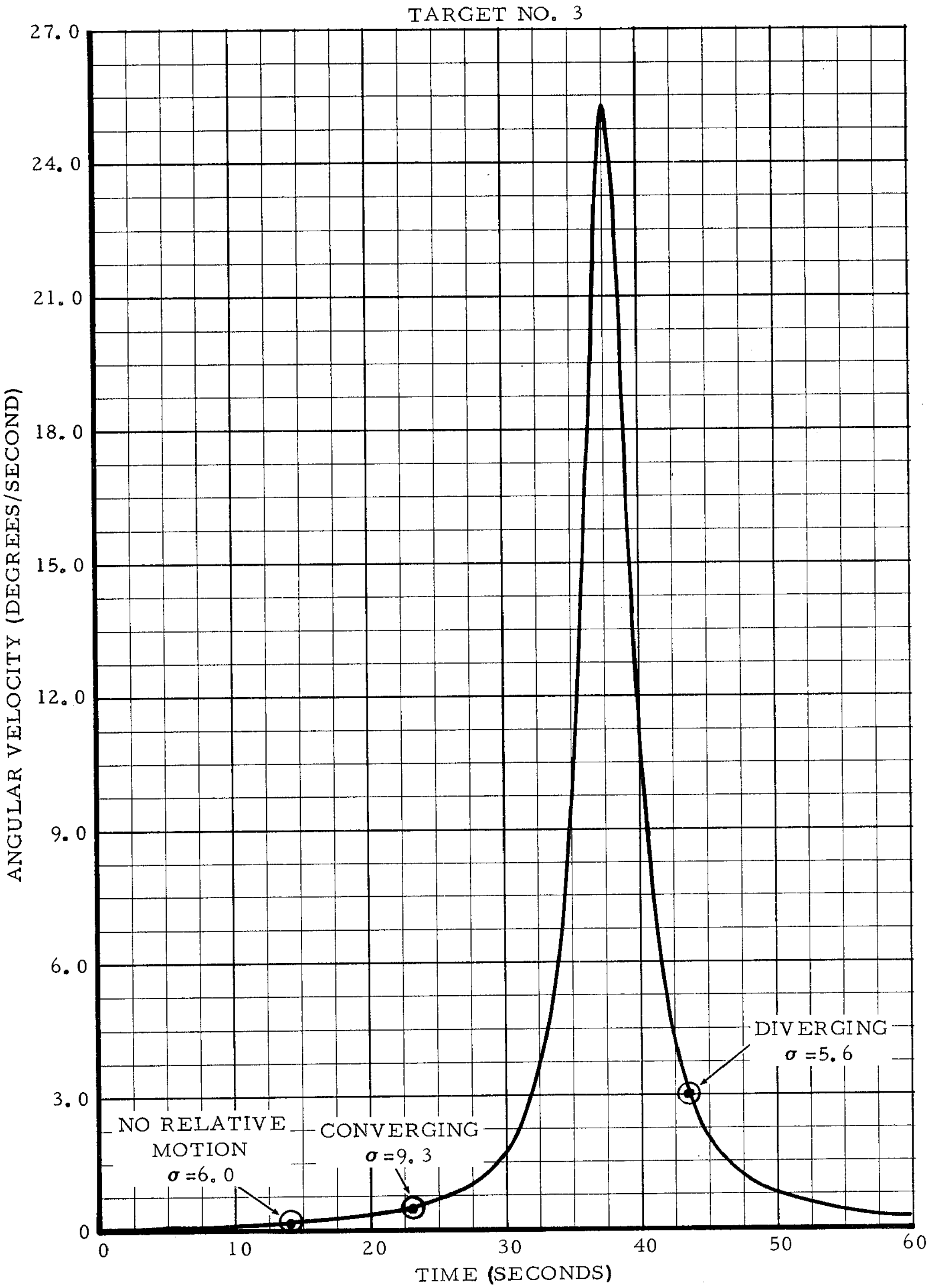

FIGURE 8 TARGET ANGULAR VELOCITY PLOT - TARGET 3

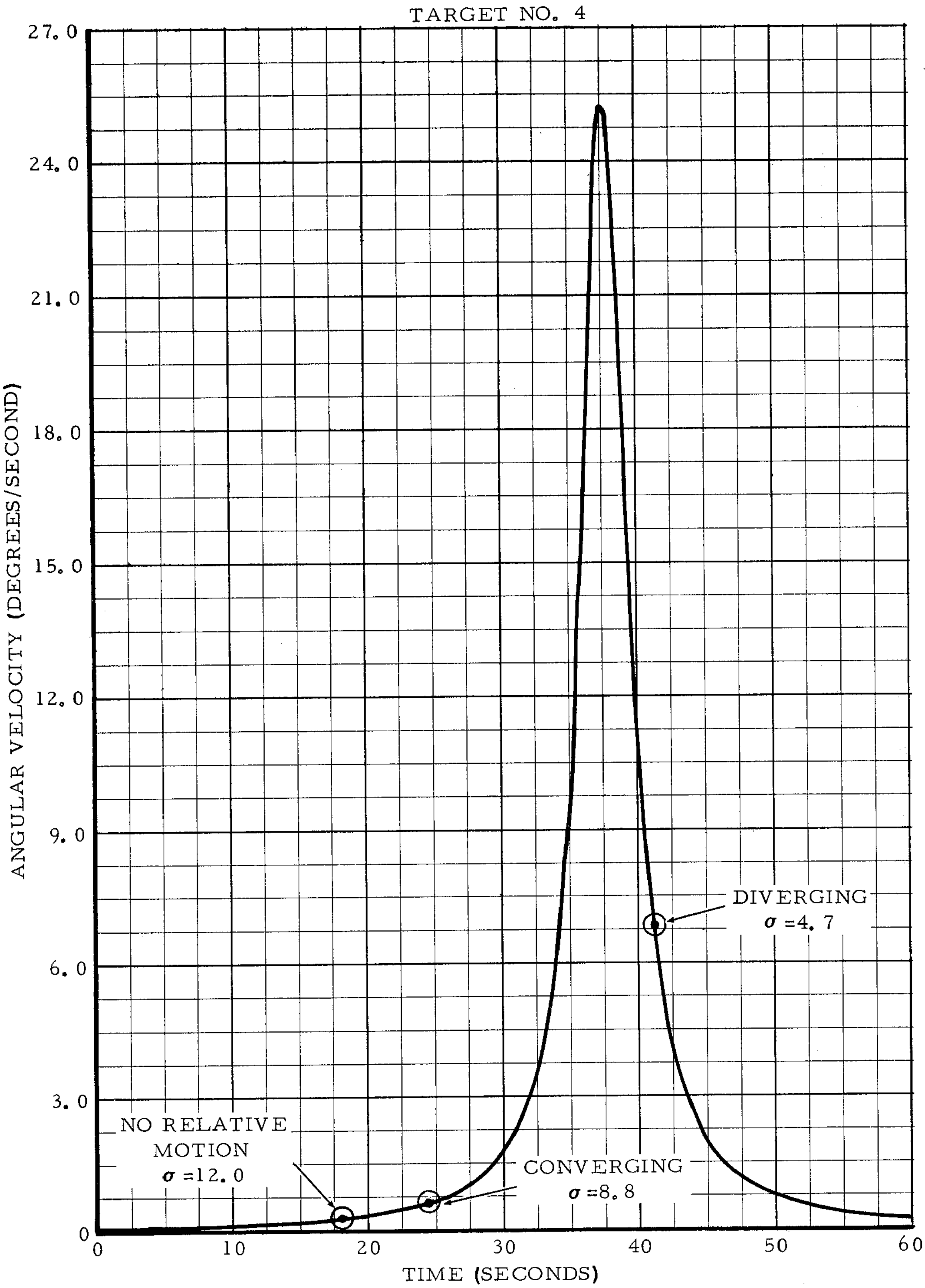

FIGURE 9 TARGET ANGULAR VELOCITY PLOT - TARGET 4

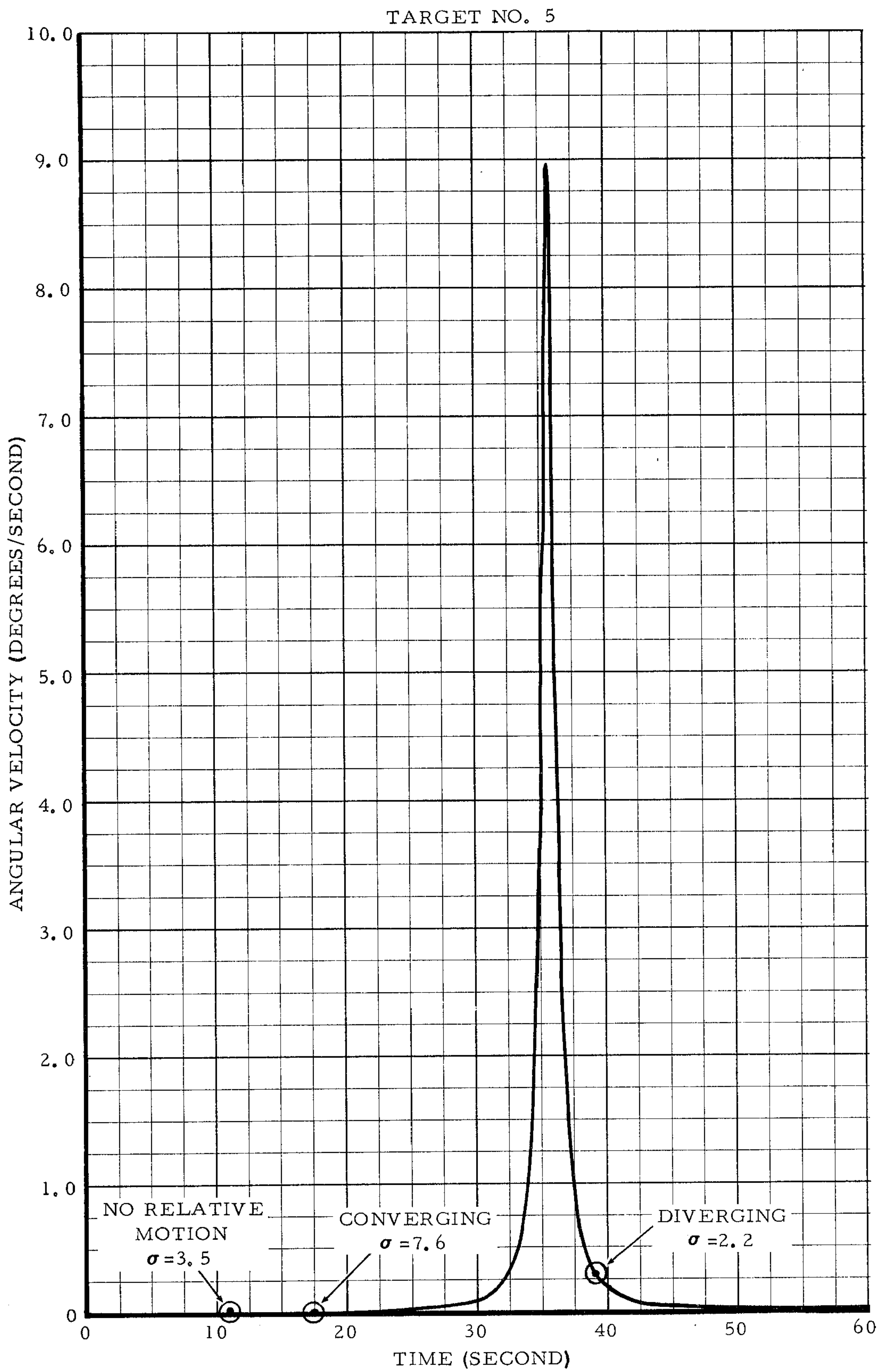

FIGURE 10 TARGET ANGULAR VELOCITY PLOT - TARGET 5

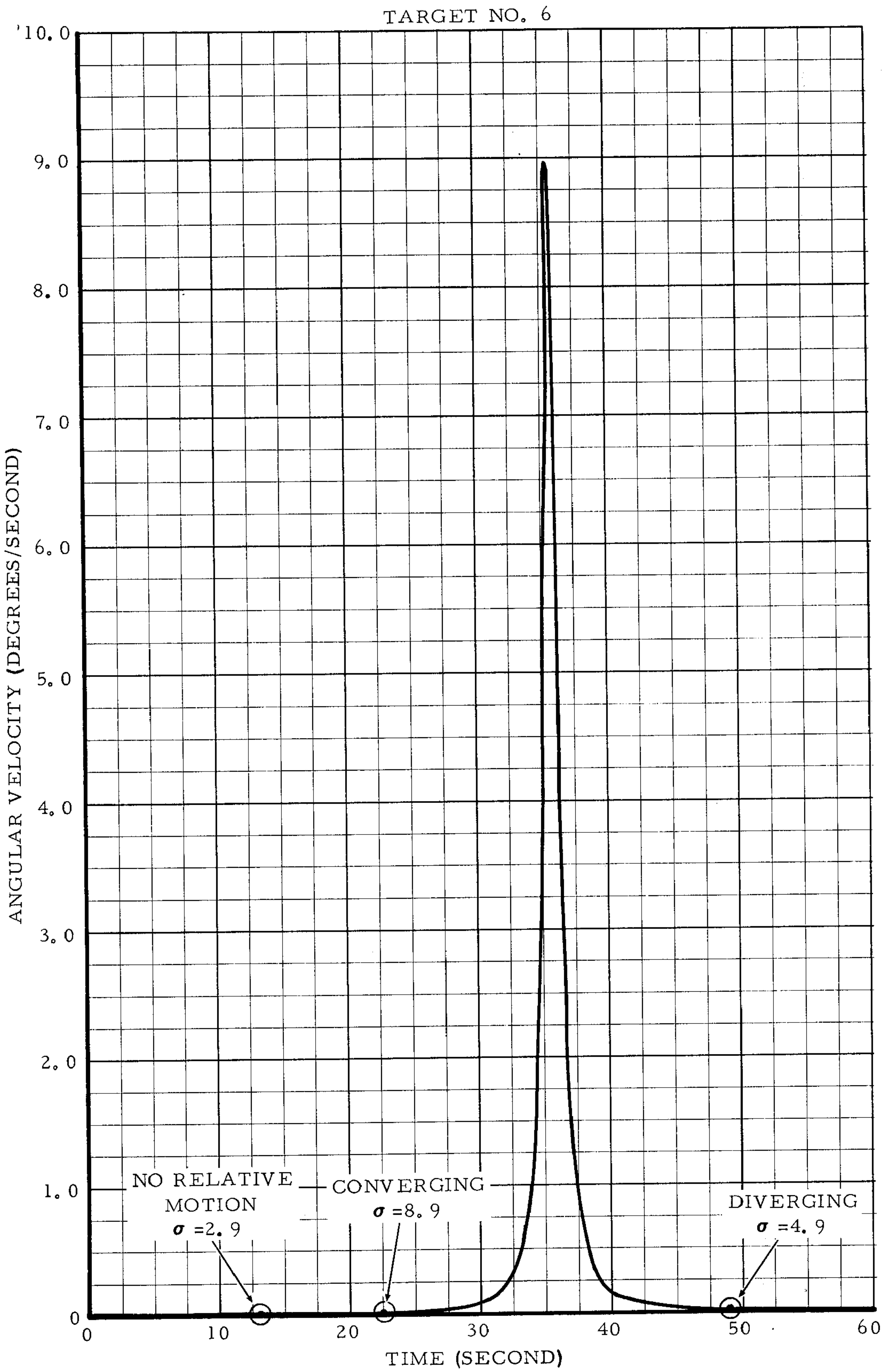

FIGURE 11 TARGET ANGULAR VELOCITY PLOT - TARGET 6