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TACTICAL UTILITY HELICOPTER INFORMATION TRANSFER STUDY

John A. Barnes

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ABSTRACT

The task requirements of the Tactical Utility Helicopter Mission have been enumerated and experienced pilots have indicated the instrumentation they feel is necessary to perform these tasks.

Film of eye movement was taken for two of the pilots while they were flying missions that incorporated these tasks. The film and the pilot replies were analyzed to provide the information transfer requirements for the Tactical Utility Helicopter flight instrumentation.

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TACTICAL UTILITY HELICOPTER INFORMATION TRANSFER STUDY[1]

INTRODUCTION

The object of this effort was to analytically determine the information needs of the flight crew of a tactical utility helicopter which could be satisfied by basic flight instrumentation. Three typical utility helicopter missions were considered in the study:

1. Utility Transport Mission
2. Rescue Mission
3. Fire Support Mission

These missions were broken into segments or tasks, such as Hover in Ground Effect, and were further micronized to include the various information requirements necessary to enable the flight crew to perform the task.

A winged helicopter was chosen for a candidate vehicle because this configuration was considered to have the performance characteristics desirable in the 1975-80 time period and because research available from other sources allowed a base for comparing studies and conclusions.

A flight crew of a pilot and copilot was used because the cost of an aircraft of this type and the importance of the various assigned missions requires operator backup to make sure the mission is completed and vehicle returned. Conventional instrumentation was referenced in this analysis as it was the only instrumentation available for study. It was beyond the scope of this study to consider other methods of presenting to the flight crew information about their aircraft's orientation in space. This limitation should not be interpreted as a recommendation for using conventional instrumentation. Any device that can present more accurate and more complete information to the flight crew should be considered as a candidate for flight instrumentation in new aircraft systems. The criteria should be to provide the flight crew with the greatest

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[1]This study was a part of a program of research sponsored by the Avionics Laboratory, U. S. Army Electronics Command, to determine information requirements for the new generation of utility helicopters.

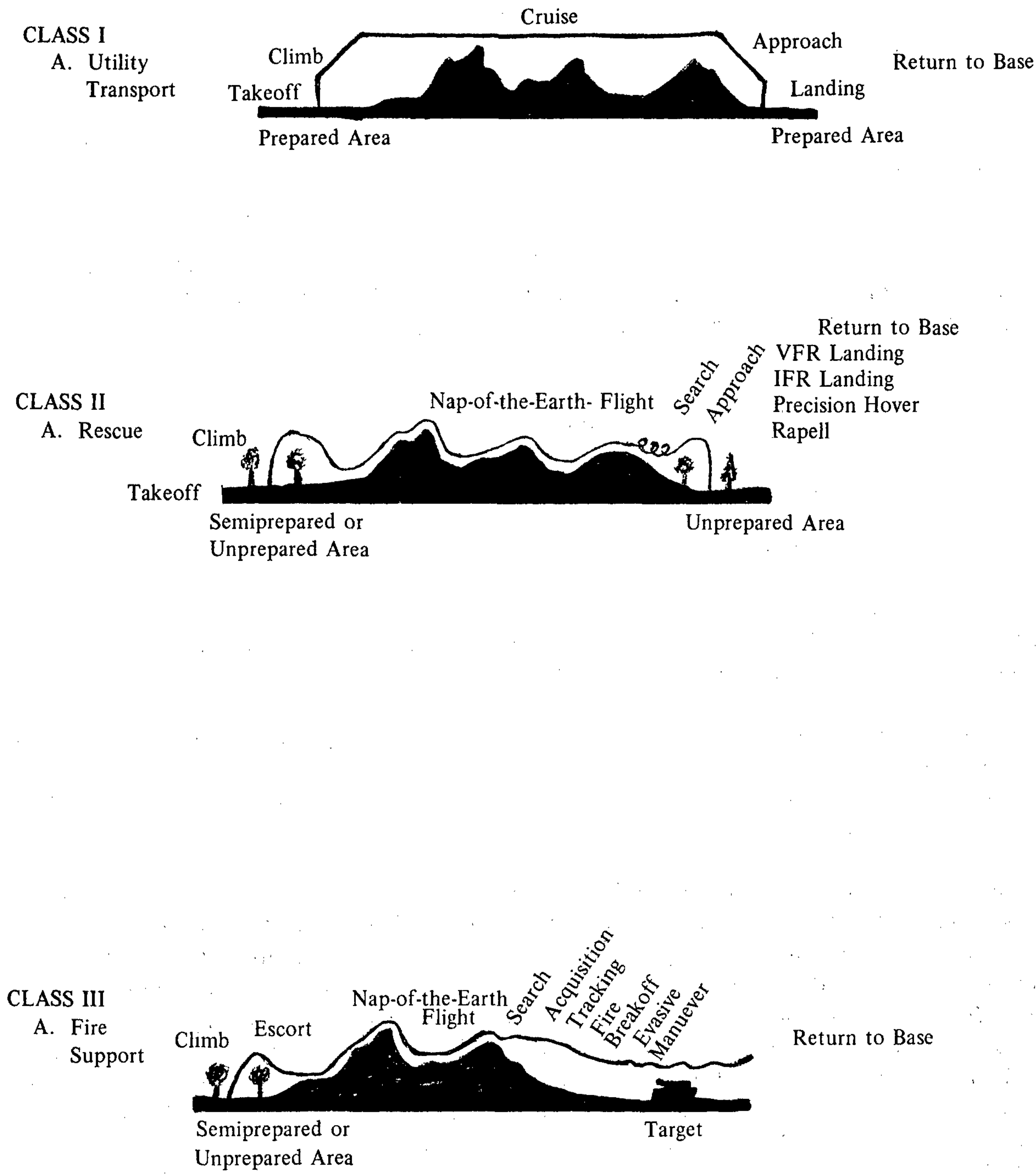


Fig. 1. MISSION PROFILES

amount of needed information in the most rapid manner with a minimum of interfaces.

The analysis was based on the specific instruments that the pilots said they used or needed to perform the mission segment tasks.

The overall analysis was verified by flights in a UH-1 aircraft using an eye-movement camera to determine which instruments the pilot used to perform specific tasks and the total amount of time each instrument was used during the performance of the task.

METHOD

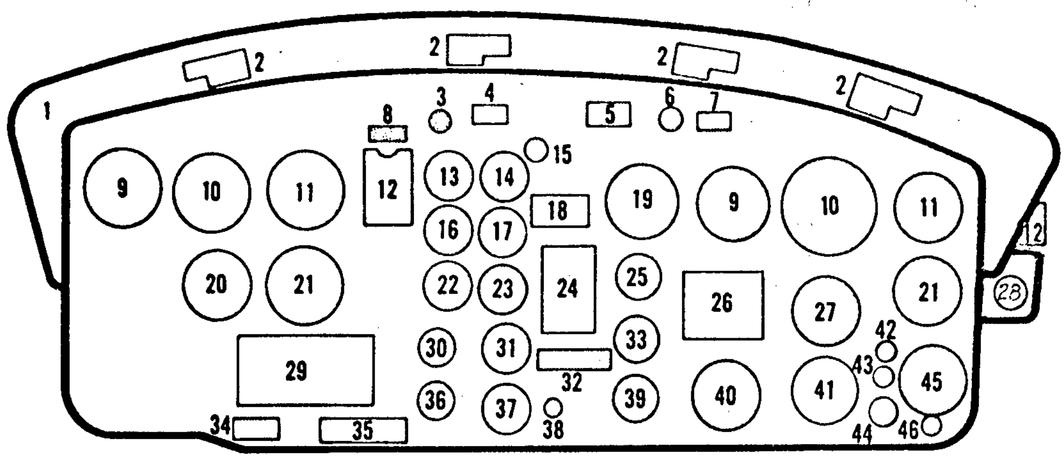
This study used USAAVLABS TR 68-39, A Study of Handling Qualities of Winged Helicopters (10) and the JANAIR Integrated Cockpit Research Program report of January 1967 (7) as a basis for the performance requirements and for the mission tasks. Each of the three missions was divided into the unique segments that would comprise that type of mission. These segments were further divided into the specific tasks required to accomplish them. The tasks were investigated as to the various motions, decisions, instruments, times, etc., to determine the information requirements of the crewmen. There were 96 separate tasks considered for the three missions; this method will allow the construction of other missions' information requirements according to the appropriate tasks identified in this study.

This initial analysis was completed by using existing information concerning the tasks, flight requirements, and instrumentation. This work was then presented to 11 pilots who had flown these types of missions in combat. Each pilot was asked to indicate the method he employed to perform the specific task; what instruments, if any, he used; and what instrumentation and/or information he felt he needed to perform the task properly. The replies were recorded on tape to facilitate the interviews and to ensure accuracy in reducing data. A standard set of 96 tasks was used by the interviewer.

To verify the analysis of crewmen's information requirements, several flights were conducted in a UH-1 during which the tasks analyzed were performed and the pilot's eye movements were recorded. The combination of these three approaches - task analysis, interviews, and inflight validation - was the basis for this report.

The 11 crewmen who acted as subjects in the interview phase of the study were highly experienced rotary wing pilots whose actual flight time in rotary wing aircraft ranged from 1000 hours to 10,000 hours. All were qualified and current in the UH-1 and several were qualified and current in the AH-1. Also in the group were several that were qualified as instrument instructor/check pilots.

Fig. 2. UH-1-B



1. Glare Shield
2. Secondary Lights
3. Engine Air Filter Light
4. Radio Call Designator
5. Master Caution Light
6. RPM Warning Light
7. Fire Detector Test Switch
8. Fire Warning Indicator Light
9. Airspeed Indicator
10. Attitude Indicator
11. Altimeter
12. Compass Correction Card Holder
13. Fuel Pressure Indicator
14. Fuel Quantity Indicator
15. Fuel Gage Test Switch
16. Engine Oil Pressure Indicator
17. Engine Oil Temperature Indicator
18. Cargo Caution Decal
19. Dual Tachometer
20. Radio Magnetic Indicator
21. Vertical Velocity Indicator
22. Transmission Oil Pressure Indicator
23. Transmission Oil Temperature Indicator
24. Pilots Check List
25. Torquemeter Indicator
26. Go-No-Go Take-off Data Placard
27. Radio-Magnetic Indicator
28. Standby Compass
29. Operating Limits Decal
30. Main Generator Loadmeter
31. DC Voltmeter
32. Engine Caution Decal
33. Gas Producer Tachometer Indicator
34. Engine Installation Decal
35. Transmitter Selector Decal
36. Standby Generator Loadmeter
37. AC Voltmeter
38. Compass Slaving Switch
39. Exhaust Gas Temperature Indicator
40. Turn and Slip Indicator
41. Omni Indicator
42. Marker Beacon Light
43. Marker Beacon Volume Control
44. Marker Beacon Volume Control
45. Clock
46. Cargo Release Armed Light

Fig. 3. UH-1-B INSTRUMENT PANEL

Appendix A contains a detailed description of the tasks that were presented by the questionnaire used in the interview phase and the flight plans of the missions flown during the flight phase.

Appendix C describes how the EMC-2 eye-movement camera may be used in an actual flight environment.

Fig. 4. INSTRUMENT PANEL WITH FIXATION SPOT
(500 feet per minute climb)

RESULTS

To relate this work to other efforts in the same area, the results of the flights and interviews will be presented in a format which is quite similar to that used by Ketchel and Jenney (6). The terms used and their definitions are as follows:

PITCH ANGLE	That component of attitude which provides the angle between the aircraft's longitudinal axis and the horizontal plane.
ROLL ANGLE	That component of attitude which provides the angle of the aircraft's rotation about its longitudinal axis.
ALTITUDE	Height above the surface and/or sea level.
AIRSPEED	Aircraft movement relative to the air mass along the heading vector.
STEERING	Heading necessary to make good a desired ground track.
ANGLE OF ATTACK	The acute angle between the longitudinal axis of the helicopter and a line representing the undisturbed relative airflow.
VERTICAL VELOCITY	Rate of climb or descent.
TURN RATE	Angular velocity during a turn (3^{o} per second is a standard rate turn for aircraft considered in this study).
HOVER POSITION	Position in relation to desired reference point on the surface.
HOVER GROUND SPEED	Movement over the surface in any direction.
GROUND SPEED	Aircraft movement relative to the surface along the track vector.
TRACK	Path.
TORQUE	Power available.
RPM	Rotor and/or engine rotation speed.

ENGINE CONDITION — Engine and drive train information such as temperature and pressure readings that provide information on present engine operation.

The results of the interviews are shown in Table 1. It will be noted that there are 43 tasks listed instead of the 96 tasks referenced previously; many of the tasks differed only slightly in parameters of performance from other similar tasks. When the results of the interviews were compiled, it was found that they could be presented using 43 tasks without loss of pertinent information. Table 1 indicates the percentage of the interviewees who stated that they would require information from a specific instrument or group of instruments to perform a given task within the specified performance parameters as well as the major source of information for the task. This study used the assumption that if an item was important enough to a pilot for him to be concerned about it, then it was an item about which he required information to perform the task at hand. Therefore, Table 1 can serve as a guide for providing to the pilot the information he requires.

The flight portion of the study included 21 of the tasks from the interview phase. These tasks were:

1. Spot Hover in Ground Effect, Visual
2. Spot Hover in Ground Effect, Instruments
3. Spot Hover Out of Ground Effect
4. 360° Hovering Turn Out of Ground Effect
5. Vertical Climb
6. Vertical Descent
7. Cruise, 60K, Visual
8. Cruise, 60K, Instruments
9. Standard Rate Turn, 60K
10. Climb, 60K, 500 Feet Per Minute
11. Climb from Hover
12. Initial Descent to 500 Feet; 60K (Approach)
13. Reverse Direction of Flight, 60K

TABLE 1

Information Requirements
(Percent of subjects indicating a requirement for specific information)

Task / Information	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
0 to 3 Knots																		
Spot Hover IGE, Visual	9	9	9						27	27	18	18		73	82	36	91	9
Spot Hover IGE, Visual	9	9	9		18			9		18	18	18		64	82	27	91	9
Spot Hover OGE, Visual	9	9	73	27	91		9			27	55	27	36	36	36	27	82	18
360° Hovering Turn IGE	27	27	55	18	91		9	27		9	64	9	27	64	64	27	91	9
360° Hovering Turn OGE	36	36	55	18	91			18		9	73	9	18	64	64	27	91	9
Vertical Climb	36	36	64		73		73			18	45	18	27	73	73	36	82	18
Vertical Descent	36	36	64	9	73		91				45		27	55	73	27	73	27
3 to 60 Knots																		
Cruise, Visual	73	73	91	100	100		82	36			82		27	55	45	45	55	45
Cruise, Instruments	91	91	91	100	100		91	36			91		36	55	45	36		100
Standard Rate Turn	100	100	100	100	100		73	82			82		36	27	27	18		100
Climb, 500 Feet per Minute	73	73	91	82	91		100	27			73		18	55	27	9		100
Climb from Hover	64	64	64	55	73		91	18			64		9	82	55	18		100
Climb, Instruments	82	82	82	73	100		100	9			73		27	73	36	18		100
Initial Descent, Visual	45	45	45	82	91	18	91	9			64		27	55	27	9	73	27
Initial Descent, Instruments	82	82	91	91	100	18	91	18		18	82	18	45	73	27	18	18	82
Final Approach	18	18	18	55	18		64			27	18	27		36	36	9	91	9
Assault Landings	27	27	45	82	55		64			45	36	45	18	73	64	18	82	18
Deceleration	27	27	64	64	91		27	9			64		27	82	36		64	36
Reverse Direction of Flight	82	82	64	73	45		18	91			36		9	64	45	27	36	64

TABLE 1 (Continued)

Task	Information																	
	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
Gunnery Run	44	44	22	77	33	33	56	11			33			18	33	9	82	18
Tear Drop Maneuver	73	73	36	64	27		55	27		27	27	27		27	36	9	91	9
Breakoff Maneuver	45	45	45	55	36		82	27			27		9	73	55	36	73	27
Autorotation, Visual	18	18	36	91	27		27			27	27	27		9	100	18	91	9
Autorotation, Instruments	91	91	73	91	100		82	9			82		36	36	100	18		
<u>60 to 150 Knots</u>																		
Cruise, Visual	55	55	100	91	100		55	27			64	45	45	55	45	45	64	36
Cruise, Instruments	91	91	100	100	100		100	36			82		36	36	45	27		100
Standard Rate Turn	100	100	100	100	100		64	82			73		36	36	36	18		100
Terrain Following, Visual	9	9	45	45	55		9	45			45		9	45	27	18	100	
Nap-of-the-earth Flight	9	9	49	36	55		9	9			36		18	55	45	36	100	
Climb Visual	73	73	91	82	82		100	18			64		18	64	36	18	18	82
Climb, Instruments	82	82	82	82	100		100	9			73		36	64	55	27		100
Climb, 500 Feet per Minute	73	73	82	91	91		100	27			73		18	55	27	18	18	82
Descent, Instruments	73	73	82	81	100	33	91	27			91		36	73	36	18		100
Standard Rate Turn, Instruments	91	91	100	73	100		91	100			82		27	45	27	18		100
Target Tracking	44	44		44	33	33	56	11			22		11		11		100	
Target Acquisition	25	25		25	63	38	25		13		50	13	13				100	
Break Off Maneuver	60	60	40	50	60		90	20			40		20	90	60	40	70	30
Acceleration	64	64	64	55	73		55		9		73	9		82	45	18	36	64
Reverse Direction of Flight	82	82	82	82	55		27	100			36		18	73	64	36	45	55
Teardrop Maneuver	73	73	45	82	27		45	36	27		27	27		36	36	9	82	18
Gunnery Run	45	45	9	64	55	18	64	9			45		9	18	27	9	82	18
Autorotation, Visual	27	27	27	91	19		45		27		27	27		9	100	18	82	18
Autorotation, Instruments	100	100	91	91	100		82				91		45	27	100	9		100

14. Cruise, 100K, Visual

15. Cruise, 100K, Instruments

16. Standard Rate Turn, 100K

17. Terrain Following, 100K

18. Climb, 100K, 500 Feet Per Minute

19. Descent, 100K, 500 Feet Per Minute

20. 180° Descending Turn, 100K

21. Reverse Direction of Flight, 100K

Table 2, which was extracted from Table 1, shows the response of the pilots interviewed to the above tasks. The numbers represent the percentage of the pilots that expressed a desire for information "information requirement" about the listed item in order to perform the task. The value given in the table referred to the use of a device presently installed in the UH-1 to provide the information or to a desired device to provide the information. Two categories which are not mentioned in other studies have been added to this table; they are the source of information used to perform the task:

EXTERNAL SOURCE - information source is outside the cockpit

INTERNAL SOURCE - information source is inside the cockpit.

Hence for a task such as SPOT HOVER, we find that 91 percent of the pilot's information comes from an external source.

Table 3 presents the percentage of time the pilots used the various available sources of information while actually performing the tasks in the UH-1 helicopters. This data was obtained from eye-movement camera film taken during the time the pilots were actually flying the UH-1.

A task-by-task comparison of these two tables provides a clear indication of what the contemporary helicopter pilot feels his information requirements are and where he obtains this information. Figures 1B through 21B in Appendix B present the information from Table 3 in graphic form.

In many cases it will be found that the sum of the part times exceeds 100 percent; this was due to the pilot fixating at a point in the flight instrument section of the instrument panel adjacent to several instruments and looking at more than one instrument without moving his fixation point. Hence, the data reflected that he was looking at

TABLE 2

Percent Requirements
(Percent of subjects indication a requirement for specific information)

Task \ Information	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
Spot Hover IGE Instructions	This task was not included in the interviews.																	
Spot Hover IGE Visual	9	9	9						27	27	18	27		73	82	36	91	9
Spot Hover OGE	9	9	73	27	91		9			27	55	27	36	36	36	27	82	18
360° Hovering Turn OGE	36	36	55	18	91			18		9	73	9	18	64	64	27	91	9
Vertical Climb	36	36	64		73		73			18	45	18	27	73	73	36	82	18
Vertical Descent	36	36	64	9	73		91				45		27	55	73	27	73	27
Cruise, 60K, Visual	73	73	91	100	100		82	36			82		27	55	45	45	55	45
Cruise, 60K, Instruments	91	91	91	100	100		91	36			91		36	55	45	36		100
Standard Rate Turn, 60K	100	100	100	100	100		73	82			82		36	27	27	18		100
Climb, 60K, 500 FPM	73	73	91	82	91		100	27			73		18	55	27	9		100
Climb from Hover	64	64	64	55	73		91	18			64		9	82	55	18		100
Initial Descent to 500 Feet	82	82	91	91	100	20	91	18		18	82	18	45	73	27	18	18	82
Reverse Dir. of Flight, 60K	82	82	64	73	45		18	91			36		9	64	45	27	36	64
Cruise, 100K, Visual	55	55	100	91	100		55	27			64		45	45	55	45	64	36
Cruise, 100K, Instruments	91	91	100	100	100		100	36			82		36	36	45	27		100
Standard Rate Turn, 100K	100	100	100	100	100		64	82			73		36	36	36	18		100
Terrain Following, 100K	9	9	45	45	55		9	45			45		9	45	27	18	100	
Climb, 100K, 500 FPM	73	73	82	91	91		100	27			73		18	55	27	18	18	82
Descent, 100K, 500 FPM	73	73	82	91	100	33	91	27			91		36	73	36	18		100
180° Descending Turn, 100K	91	91	100	73	100		91	100			82		27	45	27	18		100
Reverse Dir. of Flight, 100K	82	82	82	82	55		27	100			36		18	73	64	36	45	55

TABLE 3

Percent of Time Pilots Used Specific Instruments While Performing Given Tasks in Actual Flight

Task / Instrument	Attitude Indicator	Altimeter	Airspeed Indicator	Compass	Vertical Velocity	Rate of Turn	Torque Meter	Dual Tachometer	Engine Instruments	External References
Spot Hover IGE Visual	3	2	1	2	2	1	2	2	1	85
Spot Hover IGE Instruments	25	12	7	18	12	3	15	13	11	
Spot Hover OGE	27	22	17	17	20	2	11	12	7	
360^{o} Hovering Turn OGE	15	19	9	1	5		5	5	3	38
Vertical Climb	29	30	9	7	20	3	7	6	5	
Vertical Descent	4	5	4	3	1		2	4	7	75
Cruise, 60K, Visual	10	8	7	13	7	1	5	4	4	48
Cruise, 60K, Instruments	23	21	12	14	10	2	8	8	11	
Standard Rate Turn, 60K	23	18	9	19	9	7	6	6	6	
Climb, 60K, 500 FPM	19	17	11	19	19	2	8	6	7	
Climb from Hover	23	23	7	6	16	3	6	5	4	15
Initial Descent to 500', 60K	31	27	24	17	24		6	7	10	
Reverse Dir. of Flight, 60K	23	18	9	19	9	7	6	6	6	
Cruise, 100K, Visual	10	8	7	13	7	1	5	4	4	48
Cruise, 100K, Instruments	23	21	10	15	10	2	4	5	5	
Standard Rate Turn, 100K	14	25	2	25	14	1	3	3	3	
Terrain Following, 100K	2	2	2	2	2		2	2	2	85
Climb, 100K, 500 FPM	8	15	13	10	12	3	4	9	3	
Descent, 100K, 500 FPM	27	29	16	11	17	2	6	7	7	
180^{o} Descending Turn, 100K	35	18	15	8	8	3	3	4	5	3
Reverse Dir. of Flight, 100K	14	25	2	25	14	1	3	3	3	

TABLE 4

Comparison of UCAD and HEL Findings

Display Parameters	UCAD*	HEL*
Flight Information Parameters		
Airspeed - Longitudinal	1	1
Airspeed - Lateral	1	2
Altitude - True	1	1
Altitude - Absolute	1	1
Pitch Angle	1	1
Roll Angle	1	1
Heading	1	1
Vertical Speed - True	1	1
Vertical Speed - Absolute	1	1
Sideslip	1	2
Groundspeed - Longitudinal	2	1
Groundspeed - Lateral	2	2
Angle of Attack	0	2
Normal Load Factor	0	2
Lateral Glideslope Deviation	2	2
Vertical Glideslope Deviation	2	2
Runway Position/Touchdown Point	3	3
Trim Position	3	0
Time	2	2
Propulsion System Parameters		
Engine RPM	0	2
Rotor RPM	1	1
Torque - Rotor	1	1
Torque - Fan	1	1
Percent Power	1	1
Specialized Control Parameters		
Longitudinal Acceleration	3	2
Lateral Acceleration	2	3
Pitch Angle Rate	2	2
Roll Angle Rate	2	2
Heading Rate	1	1
Vertical Acceleration	3	3

*Key: 1 = Frequently required for normal flight phases.
2 = Information required only for specific flight phases but necessary for over-all mission sources.
3 = Information required for special missions only.
0 = Not applicable.

more than one instrument (usually two) for that period of time.

Tables 5 and 6 present a grouping of the tasks which comprise a Utility Transport Mission and a Rescue mission. These tables indicate the percentage of the total time that an instrument source was used to provide the information required for the pilot to perform the task at hand. Tasks which indicate a 100 percent usage of internal sources provide the information requirements for that task; tasks which show less than 100 percent usage of internal sources indicate that the pilot was securing additional attitude, speed, etc., information from the real world. Tasks which show a two percent usage of an instrument source indicate that this source was essentially only checked during the pilot's overall instrument check, therefore it should not be considered as a specific use of this source.

It has been the attempt of this study to present to the reader the means by which contemporary pilots obtain the information required to perform the various tasks of the tactical utility helicopter mission. Many analytical studies have spelled out the information that a pilot needs to perform specific tasks and the time-line analysis of how and when he is supposed to use this information. While this is an excellent approach, this study wanted to determine where the pilot secures this information, what source of the several available to him he uses, how much of his time is used in securing this information, and what he looks at when he views the real world for cues to maintain his desired flight path. The results section has posed an answer to all of these propositions except the last, What does the pilot use for cues in the real world?, but an analysis of the eye-movement film and postflight talks with the subjects have provided the following information concerning these cues.

Hover IGE

The film indicated that the pilot was using an intersection of the left edge of the runway and a runway seam as a target; he was using the right-hand FM antenna as a sight-device to aim at this point. This arrangement provided him the pitch, roll, vertical velocity, and over-the-ground movement information. RPM and torque or power information was obtained in a semi-gross manner by monitoring aural and tactile sensation; the proper conditions feel and sound a certain way and deviations from these sounds and feel required a check of the instruments for specific information. Under conditions where a runway is not available, the pilot uses a terrain feature in the immediate area to provide the information ordinarily obtained from the runway edge/seam intersection.

TABLE 5

Utility Transport Mission, Instrument Conditions, Percent of Time Information Required

Task / Information	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over-Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
Take Off - Climb	23	23	23	7	6	0	16	3	0	7	6	7	6	6	5	4	15	85
Cruise Instruments	23	23	21	10	15	0	10	2	0	10	15	10	15	4	5	0	0	100
Standard Rate Turn Instrument	14	14	25	2	25	0	14	1	0	2	25	2	25	3	3	3	0	100
Descent, Approach Instrument	31	31	27	24	17	18*	24	0	0	0	27	0	27	6	7	10	0	100
Land (Vertical Descent)	4	4	5	4	3	0	1	0	4	4	3	4	3	2	4	7	75	25
Mean Use for Mission	19	19	20	9	13	4*	13	1	1	5	15	5	15	4	5	6	18	82

Key: * = Desired information
2 = Routine instrument check

TABLE 6

Rescue Mission, Low Level Outbound, Instruments Return, Percent of Time Information Required

Task / Information	Pitch Angle	Roll Angle	Altitude	Airspeed	Steering	Angle of Attack	Vertical Velocity	Turn Rate	Hover Position	Over Ground Speed	Heading	Ground Speed	Track	Torque	RPM	Engine Condition	External Source	Internal Source
Take - Climb	23	23	23	7	6	0	16	3	0	7	6	7	6	6	5	4	15	85
Terrain Following	2	2	2	2	2	0	2	2	0	2	2	2	2	2	2	2	85	15
Precision Hover OGE	27	27	22	17	17	0	20	2	17	17	17	17	0	11	12	7	0	100
360° Hovering Turn OGE	15	15	19	9	1	0	5	0	38	38	1	9	1	5	5	3	38	62
Climb From Hover	23	23	23	7	6	0	16	3	0	7	6	7	6	6	5	4	15	85
Cruise, Instruments	23	23	21	10	15	0	10	2	0	10	15	10	15	4	5	5	0	100
Descent, Approach, Instrument	31	31	27	24	17	18*	24	0	0	24	17	24	17	6	7	10	0	100
Land, Vertical Descent	4	4	5	4	3	0	1	0	4	4	3	4	3	2	4	7	75	25
Mean Use for Mission	18	18	18	10	8	2*	12	1	8	14	8	10	6	5	6	5	29	71

Key: * = Desired information
2 = Routine instrument check

Terrain Following and Cruise VFR

The real-world cues for these two tasks are quite similar with possibly a rate difference due to the lower height above the terrain of the Terrain Following task. Pitch and roll can be determined fairly accurately, while heading and altitude are less accurate, and velocity approaches the gross-information category. Again the general power and engine information is determined by aural and tactile sensation. When a pilot is questioned he says he uses the horizon as a reference; this may be true, but the eye movements filmed during the four flights which recorded the above tasks show that instead of the horizon the pilot fixates on a point and/or a line of terrain features, i.e., a relief line, parallel to the horizon and perpendicular to the flight path. This line was generally at a depression angle of 20 degrees.

Running Landing

While the subjects did not do this particular maneuver, the safety pilot did and they followed the maneuver. In this maneuver the right FM antenna was again used as a sight to line up on the runway centerline, and as the aircraft approached the runway the sighting target was shifted from the centerline to the left edge of the runway and remained there until touchdown. The information obtained is essentially the same as that for hover plus vertical rate of closure.

360° Hovering Turns; Hover OGE

These maneuvers are essentially the same as far as the real-world cues are concerned. The pilots appeared to pick out a relief feature to use as a reference point/line as they had done during the terrain following and cruise tasks and they used the point to determine yaw rate. This point was used as the point to start and to complete the turn on in the first instance and as the point to aim on to prevent yaw in the other.

Vertical Descent

A point on the ground was used to determine rate of closure/descent and as a general speed, yaw and attitude reference.

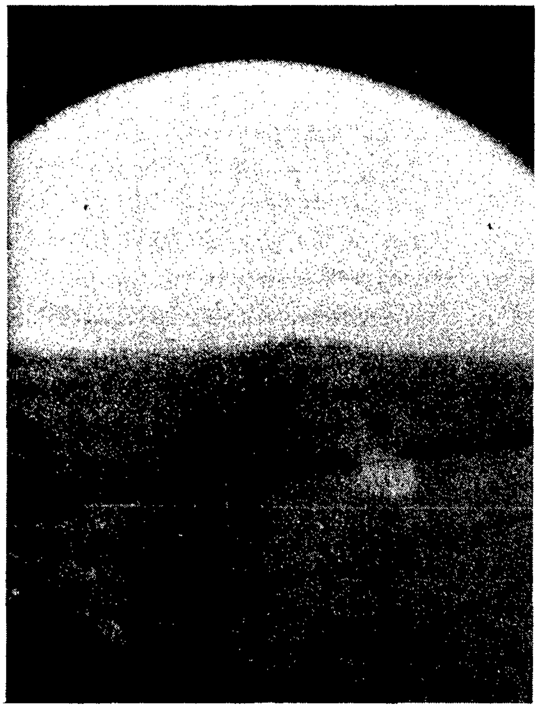


Fig. 5. FIXATION POINT, VISUAL HOVER, IN GROUND EFFECT

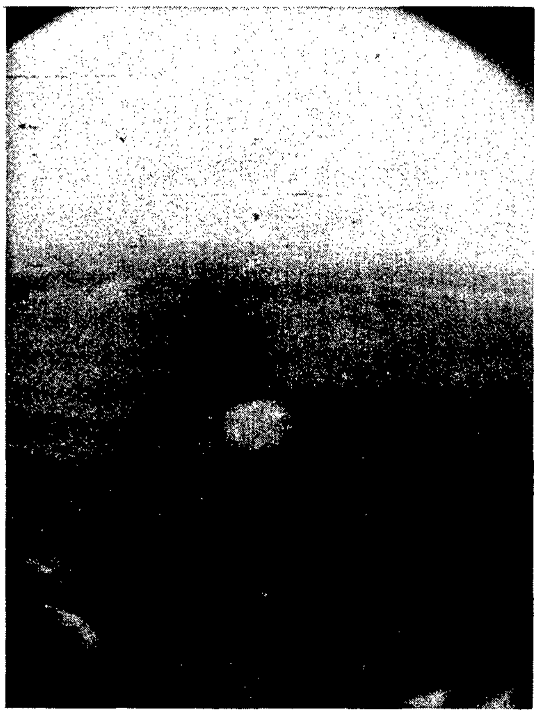


Fig. 6. FIXATION POINT, TERRAIN FOLLOWING

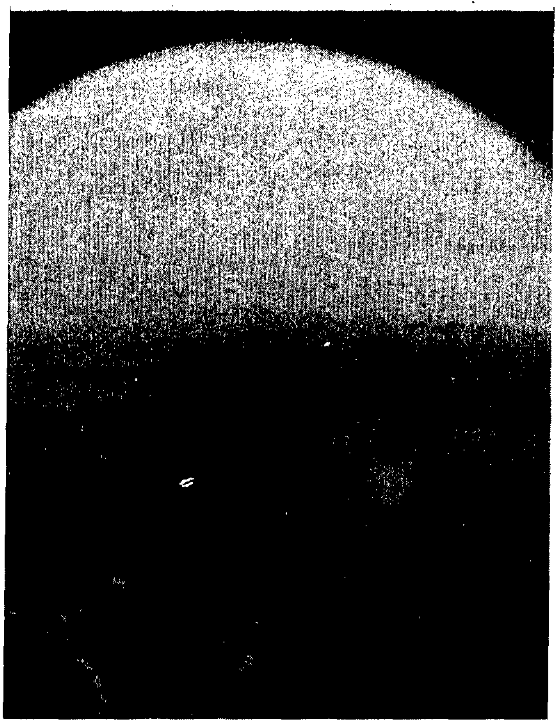


Fig. 7. FIXATION POINT, LOW LEVEL NAVIGATION

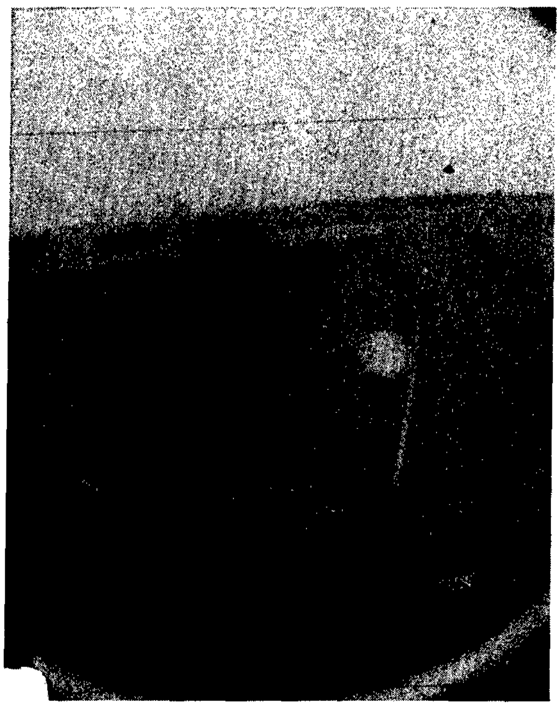


Fig. 8. FIXATION POINT, LANDING APPROACH

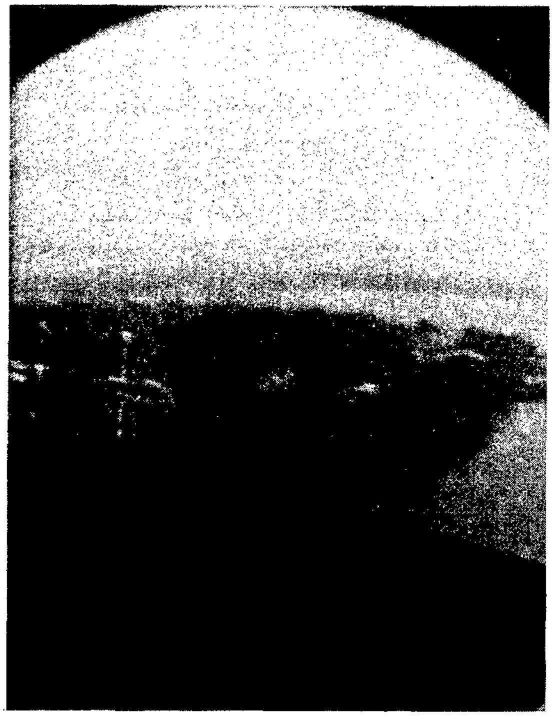


Fig. 9. FIXATION POINT, VISUAL HOVER, OUT OF GROUND EFFECT

Fig. 10. FIXATION POINT, STEEP APPROACH

One task which was not covered in the study was formation-flight IFR. A current report by Anderson, et al., (1) on this task gives the following results of a simulator study:

> The subjects were asked to estimate the percentage of time they spent observing the various instruments in both display formats. Table 19 summarizes the estimates for the Integrated Electronic Vertical Display and Table 20 the flight director display.

TABLE 19

Mean Percent Time Spent on Various Instruments

Instrument	Mean % Time
IEVD	53
Bearing Distance Heading Ind.	4
Airspeed Indicator	6
Horizontal View of Formation	7
Rate of Climb Dial	2
Altitude Indicator	28

TABLE 20

Mean Percent Time Spent on Various Instruments

Instrument	Mean % Time
Flight Director (incl. airspeed command)	48
Rate of Climb Dial	4
Bearing Indicator	4
Airspeed Indicator	3
Horizontal View of Formation (TV)	10
Altitude Indicator	31

The subjects that provided this information were five U. S. Army helicopter pilots assigned to Fort Snelling AADS, St. Paul, Minnesota.

During all of the real-world cue tasks, approximately two percent of the time was spent cross-checking the instruments, with emphasis on the engine condition group. The use of the FM antenna as a sighting device has its origins in the gunnery tasks as a reference sight for rocket firing, according to the pilots interviewed, and its use as a general sighting device has persisted. It just happens that from the pilot's seat the use of this antenna as a sighting device provides accurate information concerning the heading of the aircraft.

Several information needs were evolved from the interviews that can be satisfied by instrumentation. The expression of a need for an over-the-ground movement indicator was almost universal. In the hover tasks and very slow speed tasks, there is no accurate information available to the pilot concerning his movement in relation to the ground. For rotary wing aircraft this information should be the value of the velocity vector in the horizontal plane. Several of the subjects expressed a desire for including the Torque and RPM indicators in the flight instrument group. This preference indicates that the information should be presented to the pilot in conjunction with the attitude, altitude, vertical velocity, and airspeed information now presented by the flight group. This type of presentation would reduce the scanning task load of the pilot.

The study has not included the information requirements of such areas as communications, armament, defenses, navigation, fuel management/cruise control, trim, and radio/radar landing systems. Communication equipment and usage will depend upon future conditions and state-of-the-art, neither of which this study was equipped to handle. Armament and defense systems are in the same category as communications. Navigation was not listed as a separate requirement as the present equipment in the aircraft which is used for navigation (compass and airspeed indicator) was included. Future onboard navigation systems may change the source of navigation information but it is doubtful if the overall percentage of time usage will change. The fuel management/cruise control was a part of the engine condition information requirement. Trim was not applicable to the UH-1 and AH-1 aircraft used for this study. Trim will be a consideration for a dual-rotor aircraft and possibly for single-rotor designs other than that used on the UH-1 and AH-1. Radio/radar landing systems for future aircraft will depend upon the state-of-the-art and on what is installed in the aircraft or at the ground station, or on both. The scope of this study was such that these items could not be included.

DISCUSSION

A comparison of the results of this study with those of a current study in the same area can be made using the Terrain Following (TF) task. A study by Pelton (9) states:

> The basic items of information required for TF control of an aircraft are:
>
> 1. The elevation angle and range to all portions of the terrain profile and obstacles on or nearby the future ground track of the aircraft within ranges required for aircraft control.
>
> 2. The magnitude and direction of the vector velocity of the aircraft.
>
> 3. Aircraft attitude (pitch and roll).
>
> 4. Aircraft attitude rates (to provide control system damping).
>
> 5. Aircraft vertical acceleration.
>
> 6. Aircraft clearance above the terrain.
>
> In addition, information is needed on the static and dynamic constraints applied to the TF solution.

The subjects of this study, all of whom had performed this type of task, classified terrain following as a 100 percent external-source task; 45 percent indicated the need for precise information about airspeed, altitude (terrain clearance), and turn rate; 55 percent wanted precise steering information in addition to the visual cues; only nine percent felt that they needed precise information on attitude and vertical velocity. In addition to these items, which agree with Pelton (9), the results point out other areas of concern. Forty-five percent of the pilots indicated concern about torque and to a lesser extent, the other power/engine conditions. The sources that the pilots actually used while performing terrain following are given in Table 2. The internal sources of information were attitude indicator, altimeter, airspeed, compass, vertical velocity, torque, RPM, and engine instruments. Each of these accounted for two percent of the actual flight time, while 85 percent of the time was used observing the real world, i.e., external sources of information.

A second area called "Cruise, Visual", in this study, and "Nav" in the Pelton (9) study can also be compared. Pelton says:

> The basic items of information required for Nav control are:
>
> 1. The actual position and heading of the aircraft.

2. The desired position and heading of the aircraft.

The difference between these items is used to generate corrections in heading and speed to minimize the position and heading error which exists.

In practice, it is necessary to verify the accuracy of the position-reference system, and if it is in error to provide corrections by reference to known checkpoints on the ground.

From Table 3 we find a 60 percent/40 percent relationship for external/internal information sources; a 100 percent need for precise altitude, airspeed and steering information; a 64 percent mean need for precise vertical velocity information; and a 50 percent mean need for precise RPM, torque, and engine condition information. Actual flight data given in Table 2 indicates that 48 percent of the pilots' time was spent considering the real world; four percent of the time was concerned with engine instruments, torque and RPM; and approximately 10 percent of their time was used for each of the flight group instruments, with the exception of the rate of turn, which showed a one percent usage.

A study by Semple and Swartz (11) has also considered the Cruise task and they present the following:

INFORMATION REQUIREMENTS FOR MISSION PHASES 2 and 8
(Medium altitude flight to and from forward area)

Flight Control
- Pitch Attitude
- Roll Attitude
- Yaw
- Turn Rate
- Barometric Altitude
- Altitude Rate
- Mach
- Heading
- Engine Performance Data

Navigation
- Current Position
- Destination Position
- Bearing to Destination
- Distance to Destination
- Ground Speed
- Ground Speed

Fuel Management
- Fuel Quantity
- Fuel Flow Rate
- Distance to Destination
- Ground Speed

Defenses
- Radar
- Infrared Sensors
- ECM
- IFF

These findings agree quite closely with the results of the interviews shown in Table 1, with the exception of the navigation and defenses areas, which were not considered in the interviews. The fuel management area was listed on the interview data reduction form but no pilot mentioned this specifically (fuel quantity, fuel flow) and when they were asked the general reply was that this information was included in their engine instruments check, which is listed in this study as engine condition.

A comparison of the findings of this study and one by Williams (12) is presented in Table 4. UCAD refers to the Universal Contact Analog Display. This is a synthetically generated electronic display which provides a pictorial representation of the real world as normally seen from the cockpit window under visual flight conditions. Extensions of this concept have led to a broader interpretation of the term "UCAD" to include all television-format integrated vertical-situation displays.

A recent report on the Integrated Electronic Vertical Display (IEVD) by Woodling and Simpson (13) in which an EMC-2 eye-movement camera was used to record data from the spot hover task as performed in a simulator states the following:

> Of the 60 minutes of film, only one minute was suitable for detailed analysis. Figure 3-3 shows the distribution of fixation time that was found to exist for this 60-second hover trial. The height of each block is proportional to the percentage of time the subject spent fixating on that area of the display surface. Approximately 75% of the time was spent in or near the circle at the center of the screen. This area is the source of information on pitch, heading, turn rate, and to some extent roll. Eight percent was spent scanning the right side of the screen where altitude and rate of climb data are presented. This consisted of six fixations averaging 0.8 seconds each. Seventeen percent was spent at the left of the screen where the airspeed tape was located. The look durations averaged 0.85 second for ten fixations which are observed.
>
> Although this data is based on the only film that could be analyzed quantitatively, a qualitative impression after viewing all of the film indicates that these data are not typical. The tendency for the fixation to rest in the center is apparent throughout, and the majority of film indicates that most scanning occurs along the horizontal center line of the screen.

The time-in-use figures from the actual spot hover task given in Table 2 indicate that 46 percent of the pilot's time was used obtaining attitude, heading and turn rate information; 24 percent of the time was concerned with rate of climb and altitude; and seven percent of the time was concerned with airspeed. In addition, 39 percent of the time was spent observing the engine and power condition indicators i.e., RPM and torque and engine instruments.

A point brought out by several of the pilots interviewed concerning the method of obtaining steering information was that generally a radio beam was used as the primary steering reference. Such a beam should not be considered as a primary steering reference for combat use at the expense of a passive steering reference such as the compass system, which is not subject to jamming.

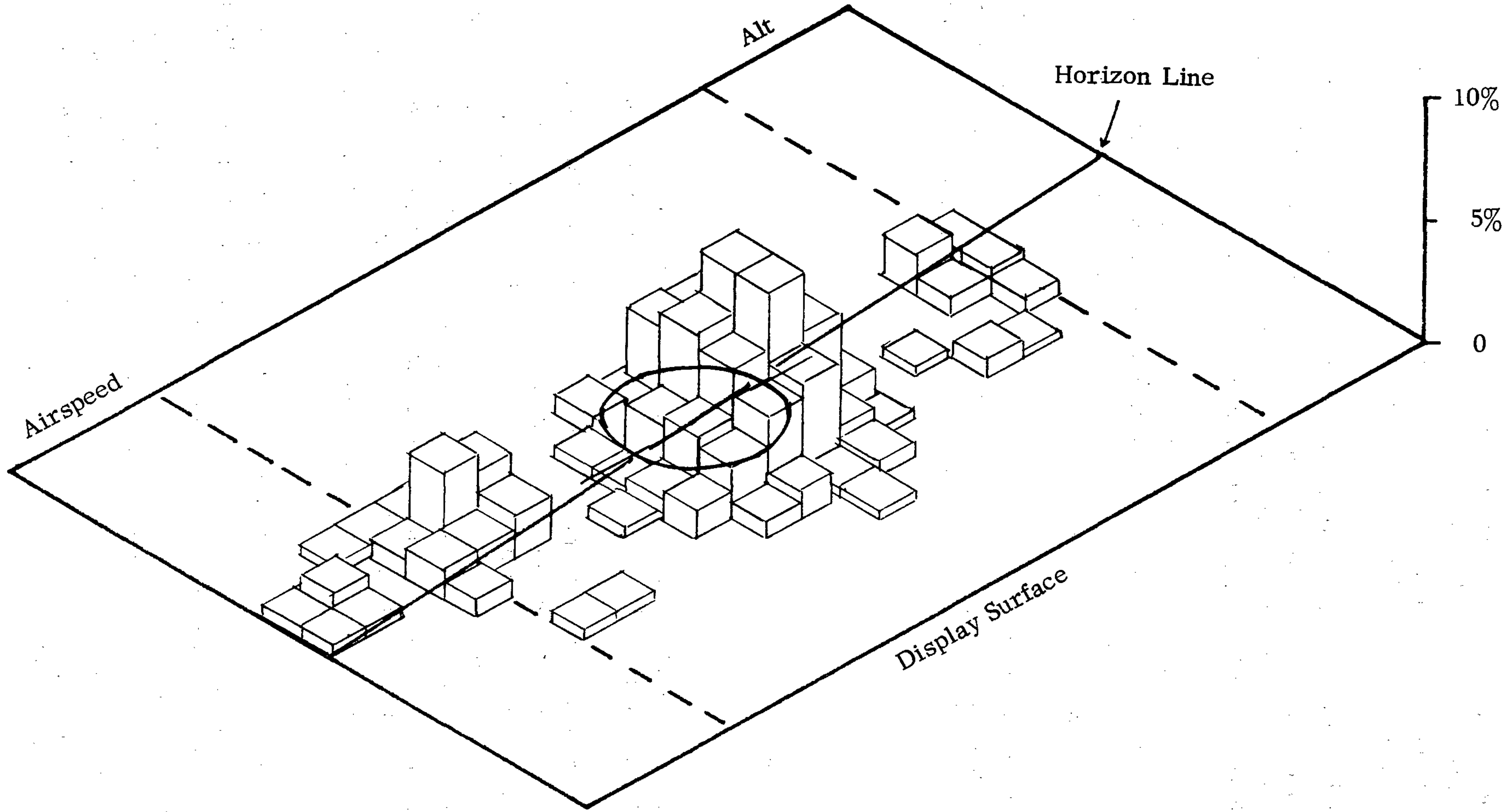


Fig. 11. FIXATION POINTS IEVD
(Referred to as Figure 3-3 in text)

The portion of the time spent considering the real world was primarily concerned with keeping track of the aircraft's flight path, actual, desired, and projected, by constant cross-reference between map and ground checkpoints. The attitude of the vehicle in relation to a horizontal reference was also considered.

A pilot generally reports that he uses the horizon as his attitude reference, but from the film data obtained in this study, it was found that at low altitude (<500 ft. absolute) the subjects consistently used a line on the ground which was essentially parallel to the horizon as a reference line for attitude and rate of closure.

Several items of information which would be required in specific flight phases have not been listed as yet in the study. Weather conditions enroute and at destination are required for safety. Fuel-management data is also certainly required information, as well as present position of the aircraft.

The subjects who had flight experience in the AH-1 expressed an opinion that this aircraft was much easier to fly than the UH-1, primarily because of its greater speed, but they said the information required to perform the given tasks was essentially the same.

SUMMARY

The study has shown what basic flight information the UH-1 pilot felt he needed to perform specific maneuvers and what instruments he used to obtain this information.

It has also determined what instruments the pilots actually used in flight to perform many of these tasks and the amount of time he spent using these instruments during each maneuver. Two typical missions of a tactical utility helicopter have been presented, maneuver by maneuver, and the estimated time spent using each of these instruments has been determined from experimental data. The need for certain information not now available with present instrumentation has been indicated. No attempt has been made to indicate in what form the various information should be presented nor have specialized areas such as armament, communications, defense, navigation, etc., been considered.

The techniques used in this study should be employed to expand the data base already established by increasing the sample size of the actual flight use of the displays now installed in U. S. Army helicopters. They should also be considered for the evaluation of new concepts such as the headup types, the contact-analog types, the television types, etc., and any other approach to information transfer that concerns the pilot of an aircraft, the operator of a vehicle, or the operator of any equipment where it is essential to present to the operator a large amount of data that must be visually screened to satisfactorily perform the desired task.

Fig. 12. AH-1

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APPENDIX A

TACTICAL UTILITY HELICOPTER MISSION TASKS

The task list presented to the subjects contained 96 tasks, many of which had only minor differences in parameters. It was felt that this redundancy of task descriptions would do nothing to enhance the report; therefore, the 43 tasks described below were selected as the primary tasks presented in the task list.

The following tasks are performed at ground speeds of 0 to 3 knots.

TASK	DESCRIPTION
SPOT HOVER (IGE), VISUAL	Keep the aircraft's C.G. within a 12 ft. radius circle, attitude $\pm 5^\circ$, upwind heading $\pm 10^\circ$, and altitude ± 5 feet.
SPOT HOVER (IGE), VISUAL	Same as above except maintain downwind heading $\pm 10^\circ$ in 30 K winds.
SPOT HOVER (OGE), VISUAL	In gusts up to 10 K, VFR maintain for 3 minutes altitude ± 10 ft., C.G. within a 10 ft. radius circle, zero ground speed ± 10 K, heading and attitude $\pm 5^\circ$.
360° HOVERING TURN (IGE)	Same as Spot Hover plus start and stop turn within $\pm 10^\circ$ of prescribed heading.
360° HOVERING TURN (OGE)	Same as above.
VERTICAL CLIMB	Same as Spot Hover plus climb at 500 feet per minute to prescribed altitude ± 5 feet.
VERTICAL DESCENT	Same as Spot Hover plus descend to prescribed altitude ± 5 feet at 500 fpm.

The following tasks are performed at airspeeds of 3 to 60 knots unless otherwise specified.

CRUISE, VISUAL	Maintain straight and level flight in light turbulence, altitude ± 20 ft., airspeed ± 5 K, heading and attitude $\pm 5^\circ$.
CRUISE, INSTRUMENTS	Same as above except altitude ± 50 ft.

TASK	DESCRIPTION
STANDARD RATE TURN	Same as above except heading, turn rate 3° per second $\pm 1^{\circ}$ per second.
CLIMB, 500 FEET PER MINUTE	Same as above except altitude, rate of climb $\pm$100 ft.
CLIMB FROM HOVER	Acceleration at least 3 K per second, heading and roll attitude $\pm 5^{\circ}$, and rate of climb at least 500 feet per minute.
CLIMB, INSTRUMENTS	Airspeed $\pm$10 K, heading $\pm 10^{\circ}$, rate of climb 500 feet per minute $\pm$100 feet per minute, and attitude $\pm 5^{\circ}$.
INITIAL DESCENT, VISUAL	At approach speed $\pm$10 K maintain 30° descent $\pm 5^{\circ}$, attitude and heading $\pm 3^{\circ}$.
INITIAL DESCENT, INSTRUMENTS	At approach speed $\pm$5 K maintain 15° descent, $\pm 3^{\circ}$, attitude and heading $\pm 3^{\circ}$.
FINAL APPROACH	Starting from descent at 100 ft. altitude, touch down within 20 ft. of desired spot at leass than 5 ft./sec. sink rate and 0-10 K ground speed, maintain upwind heading $\pm 10^{\circ}$, roll attitude $\pm 5^{\circ}$.
ASSAULT LANDINGS	From cruise speed at 1500 ft. altitude, come to landing within 15 ft. of desired spot at less than 5 ft./sec. sink rate and 0-10 K ground speed in no more than 75 sec., maintaining downwind heading $\pm 5^{\circ}$.
DECELERATION	At least 3 K/sec.
REVERSE DIRECTION OF FLIGHT	At any airspeed above 60 K establish 15°/sec. turn rate, $\pm 3^{\circ}$/sec., in no more than 5 sec., maintaining airspeed $\pm$10 K and altitude within -20 to + 50 ft.

TASK	DESCRIPTION
GUNNERY RUN	In gusts up to 10 K, and rates of descent up to 1000 fpm above 60 K. Maintain pitch attitude and heading $\pm 2^{\circ}$, roll attitude $\pm 5^{\circ}$, rate of descent ± 100 fpm.
TEAR DROP MANEUVER	From a speed of 60 K and a 3000 ft. altitude, establish maximum rate of turn and execute landing on point of maneuver initiation in no more than 25 sec. (low-speed assault landing touchdown requirement).
BREAK OFF MANEUVER	Change from 500 fpm rate of descent, ± 100 fpm, to 1000 fpm rate of climb, ± 100 fpm; and change heading 180°, $\pm 10^{\circ}$, at any airspeed above 60 K in no more than 15 sec.
AUTOROTATION, VISUAL	Starting from speed of 3 to 60 K, altitude above 300 ft., touch down within 50 ft. of desired spot, maintaining heading $\pm 15^{\circ}$, roll attitude $\pm 5^{\circ}$, touch down at less than 10 ft./sec. sink rate, and zero ground speed ± 10 K.
AUTOROTATION, INSTRUMENTS	Starting from speed of 3 to 60 K, altitude above 300 ft., touch down within 50 ft. of desired spot, maintaining heading $\pm 10^{\circ}$, roll attitude $\pm 5^{\circ}$, touch down at less than 10 ft./sec. sink rate, and zero ground speed ± 10 K.

The following tasks are performed at airspeeds of 60 to 150 knots unless otherwise specified.

TASK	DESCRIPTION
CRUISE, VISUAL	Maintain straight and level flight in light turbulence, altitude ± 20 ft., airspeed ± 5 K, and heading and attitude $\pm 5^{\circ}$.
CRUISE, INSTRUMENTS	Same as above except maintain altitude ± 50 ft.
STANDARD RATE TURN	Same as Cruise except heading, yaw rate $\pm 1^{\circ}$/sec.
TERRAIN FOLLOWING, VISUAL	Follow moderate terrain features (average ridge-to-valley distance 2400 ft., average slope 7.5°) within 20 to 100 ft. at cruise speed, ± 10 K maintaining heading $\pm 10^{\circ}$.
NAP-OF-THE-EARTH FLIGHT, VISUAL	At 80 K ± 10 K, follow local terrain features with maneuvers from 0.5 to 2.5 g's, controlling flight path altitude ± 10 ft., and heading $\pm 5^{\circ}$.
CLIMB, VISUAL	Acceleration at least 3 K/sec. heading and roll attitude $\pm 5^{\circ}$ rate of climb at least 500 fpm.
CLIMB, INSTRUMENTS	Climb airspeed ± 10 K, heading $\pm 10^{\circ}$, attitude $\pm 5^{\circ}$, rate of climb 500 fpm, ± 100 fpm.
CLIMB, 500 FEET PER MINUTE	Same as Cruise except altitude, rate of climb ± 100 fpm.

TASK	DESCRIPTION
DESCENT, INSTRUMENT	From cruise, establish a rate of descent of 500 fpm, $\pm$100 fpm, attitude $\pm 5^{o}$, airspeed $\pm$10 K, heading $\pm 10^{o}$.
STANDARD RATE TURN, INSTRUMENT	Turn 3^{o}/sec. $\pm 1^{o}$/sec. at 500 fpm rate of descent, $\pm$100 fpm, maintaining airspeed $\pm$10 K, attitude $\pm 5^{o}$. Roll out at desired heading $\pm 10^{o}$.
TARGET TRACKING	Maintain pitch attitude and heading $\pm 2^{o}$, roll attitude $\pm 5^{o}$, rate of descent $\pm$100 fpm at rates of descent up to 1000 fpm.
TARGET ACQUISITION	Stabilize change in heading of 20^{o} in no more than 10 sec. to allowances in target tracking.
BREAK OFF MANEUVER	Change from 1000 fpm rate of descent, $\pm$100 fpm, to 2000 fpm rate of climb, $\pm$100 fpm, and change heading 180^{o}, $\pm 10^{o}$, at any airspeed above 60 K in no more than 15 sec.
ACCELERATION	Accelerate to cruise speed $\pm$10 K at an average of at least 2 K/sec., maintaining roll attitude $\pm 5^{o}$, heading $\pm 10^{o}$.
REVERSE DIRECTION OF FLIGHT	Maintain airspeed $\pm$5 K and altitude $\pm$20 ft. in a 3^{o}/sec., $\pm 1^{o}$/sec., turn.
TEARDROP MANEUVER	From cruise, establish maximum rate of turn and pass over point of maneuver initiation, maintaining airspeed $\pm$10 K and altitude $\pm$20 ft. in no more than 30 sec.
GUNNERY RUN	In gusts up to 10 K, and rates of descent from 0 - 1000 fpm, above 60 K. Maintain pitch attitude and heading $\pm 5^{o}$, roll attitude $\pm 5^{o}$, rate of descent $\pm$100 fpm.

TASK	DESCRIPTION
AUTOROTATION, VISUAL	At any airspeed, up to V_{max}, establish engine-out rate of descent of 500 fpm, $\pm$100 fpm. Maintain pitch and roll attitude $\pm 5^o$, he ading $\pm 10^o$.
AUTOROTATION, INSTRUMENTS	At any airspeed, up to V_{max}, establish engine-out rate of descent of 500 fpm, $\pm$100 fpm. Maintain pitch and roll attitude $\pm 5^o$, heading $\pm 5^o$.

Both of the experimental pilots were briefed to fly three missions; one using Flight Plan I, one using Flight Plan II. A backup mission was flown in case one of the planned missions developed trouble. During the flight phase each pilot experienced a film breakage; therefore, the pilots flew one mission each, using Plans I and II.

Tables 1A and 2A give Mission Plan I and Mission Plan II. Figures 1A and 2A show Flight Profile I and Flight Profile II. Tables 3A through 6A give the missions as flown and the actual times involved. It can be seen that both mission plans were followed quite closely with the only deviation being the addition of three minutes of terrain following to Plan II in pace of the vertical descent. It was felt that the vertical descent had been done in Plan I and not adding to the experiment while the terrain following did add to the data.

The results of the interviews were recorded on the data-reduction form shown in Figure 3A. Each task was given a number for ease of recording and positive responses were recorded in the appropriate spaces.

TABLE 1A

Mission Plan I, Flown at 60 Knots or Less

MANEUVER	START	END
Take Off	00:00	
Hover, IGE	00:00	00:02
Vertical Climb	00:02	00:04
Cruise, IFR	00:04	00:07
Standard Rate Turn, IFR	00:07	00:08
Climb, IFR	00:08	00:09
Cruise, IFR	00:09	00:12
180^{o} Turn, IFR	00:12	00:13
Steep Approach IFR	00:13	00:15
Hover, OGE, VFR	00:15	00:16
Vertical Descent	00:16	00:18
Land		00:19

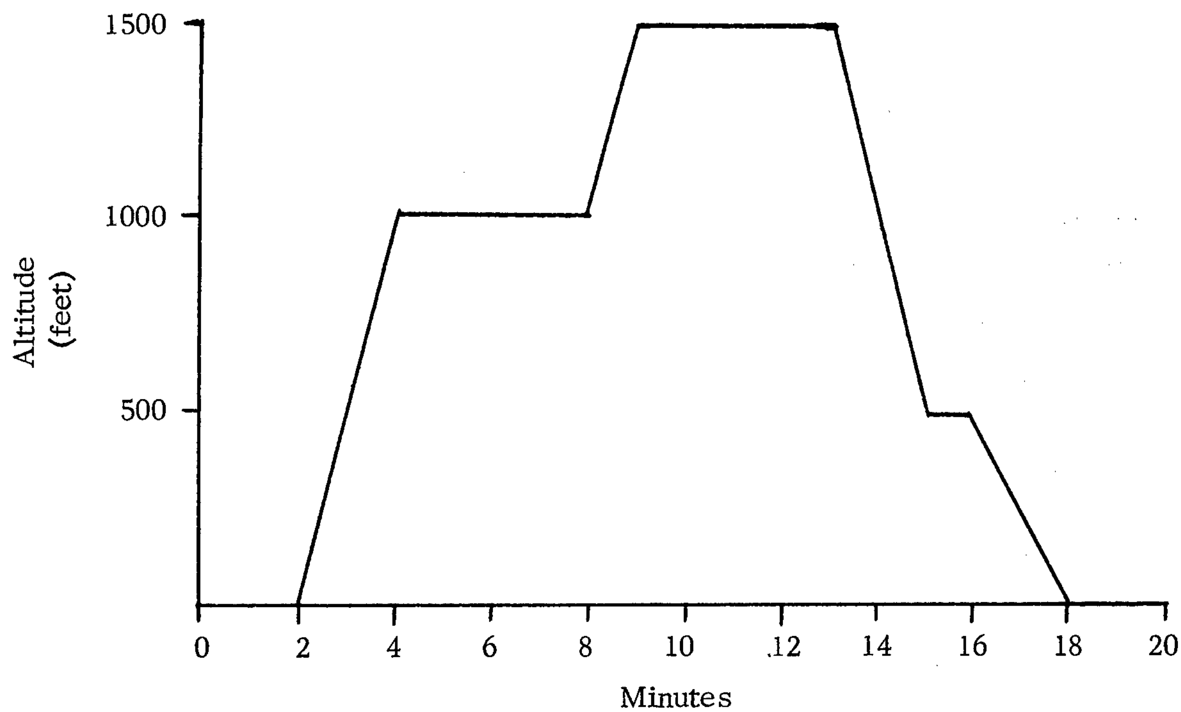

Fig. 1A. PROFILE OF MISSION PLAN I

TABLE 2A

Mission Plan II, Flown at 100 Knots or Greater

MANEUVER	START	END
Take Off	00:00	
Climb, IFR	00:00	00:03
Cruise, IFR	00:03	00:06
Standard Rate Turn	00:06	00:07
Cruise, IFR	00:07	00:10
Descent, IFR	00:10	00:12
Descending Turn, IFR	00:12	00:13
360° Hovering Turn, VFR	00:13	00:16
Descent	00:16	00:18
Land		00:19

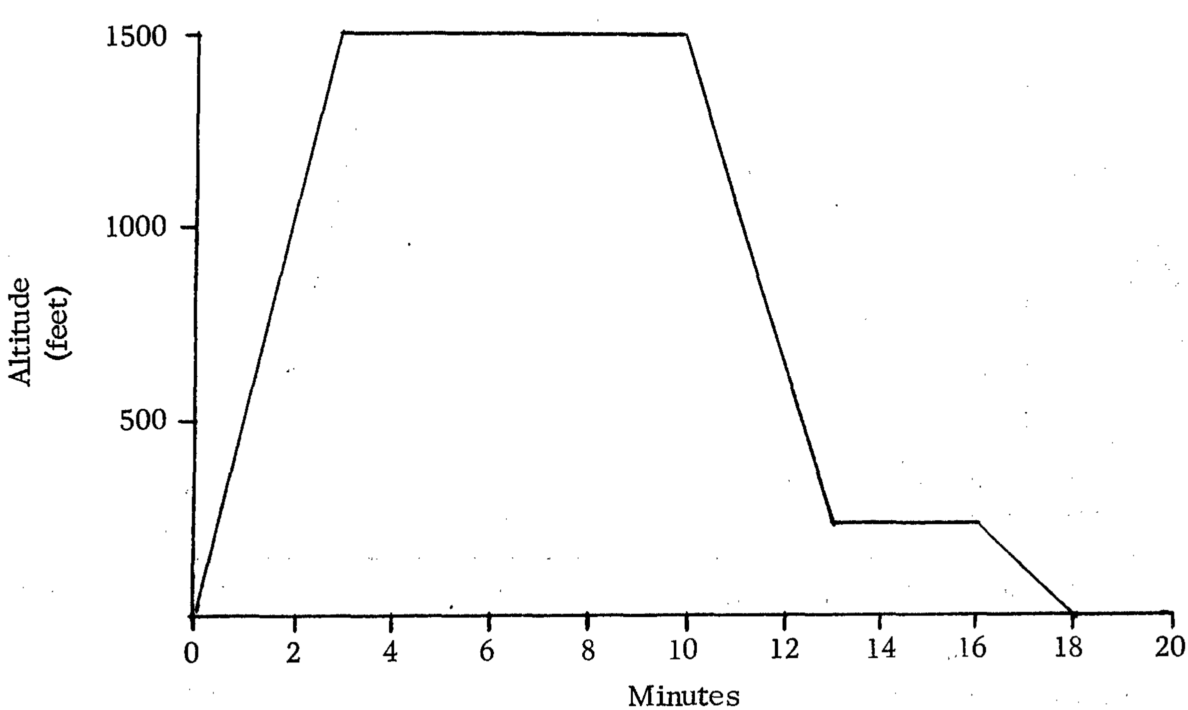

Fig. 2A. PROFILE OF MISSION PLAN II

TABLE 3A

Flight 1, Plan I, 2 June 1969

MANEUVER	START	END
Take Off	10:25	
Camera On	10:26	
Hover, IGE	10:27	10:29
Vertical Climb	10:29	10:31
Cruise, IFR	10:31	10:34
Standard Rate Turn, IFR	10:34	10:35
Climb, IFR	10:35	10:36
Cruise, IFR	10:36	10:39
180^o Turn, IFR	10:39	10:40
Steep Approach, IFR	10:40	10:42
Hover, OGE, VFR	10:42	10:43
Cruise, VFR	10:43	10:46
Vertical Descent, VFR	10:46	10:47
Land		10:50
Cameras Off		10:50

TABLE 4A

Flight 3, Plan II, 6 June 1969

MANEUVER	START	END
Take Off	09:49	
Cameras On	09:49	
Climb, IFR	09:51	09:54
Cruise, IFR	09:54	09:57
Standard Rate Turn, IFR	09:57	09:58
Cruise, IFR	09:58	10:01
Descent, IFR	10:01	10:03
Descending Turn, IFR	10:03	10:04
Hover, OGE	10:04	
360^o Hovering Turn	10:05	10:07
Terrain Following	10:07	10:10
Land		10:11
Cameras Off		10:11

TABLE 5A

Flight 4, Plan I, 9 June 1969

MANEUVER	START	END
Take Off	08:56	
Cameras On	08:57	
Hover	08:57	08:59
Vertical Climb	08:59	09:01
Cruise, IFR	09:01	09:04
Standard Rate Turn, IFR	09:04	09:05
Climb, IFR	09:05	09:06
Cruise, IFR	09:06	09:09
180^{o} Turn, IFR	09:09	09:10
Steep Approach, IFR	09:10	09:12
Hover, OGE, VFR	09:12	09:13
Vertical Descent, VFR	09:13	09:14
Cruise, VFR	09:14	09:17
Land		09:18
Cameras Off		09:18

TABLE 6A

Flight 5, Plan II, 11 June 1969

MANEUVER	START	END
Take Off	08:55	
Cameras On	08:55	
Climb, IFR	08:56	08:59
Cruise, IFR	08:59	09:02
Standard Rate Turn, IFR	09:02	09:03
Cruise, IFR	09:03	09:06
Descent, IFR	09:06	09:08
Descending Turn, IFR	09:08	09:09
360^{o} Hovering Turn	09:09	09:11
Terrain Following	09:11	09:14
Land		09:15
Cameras Off		09:15

TACTICAL UTILITY HELICOPTER INSTRUMENTS

SUBJECT____________________ DATE____________

	TASK #										
1	ALTIMETER										
2	AIRSPEED										
3	ATTITUDE INDIC.										
4	VERTICAL VELOC.										
5	MAGNETIC COMPASS										
6	STANDBY COMPASS										
7	RADIO COMPASS										
8	COURSE INDICATOR										
9	BEARING/HEADING										
10	DUAL TACHOMETER										
11	ENGINE OIL PRESS.										
12	ENGINE OIL TEMP.										
13	TRANS. OIL PRESS.										
14	TRANS. OIL TEMP.										
15	GAS PROD. TACH										
16	EXHAUST TEMP.										
17	TORQUEMETER										
18	VOLTMETER										
19	LOADMETER										
20	CLOCK										
21	FUEL QUANTITY										
22	FREE AIR TEMP.										
23											
24											

Fig. 3A. DATA REDUCTION FORM

APPENDIX B

TIME-BASED USE ANALYSIS

The graphs presented in this section indicate the percentage of time each instrument was used by the subject pilots while performing the particular maneuvers. They represent the sources from which the pilots satisfied their information requirements.

TIME-BASED USE ANALYSIS

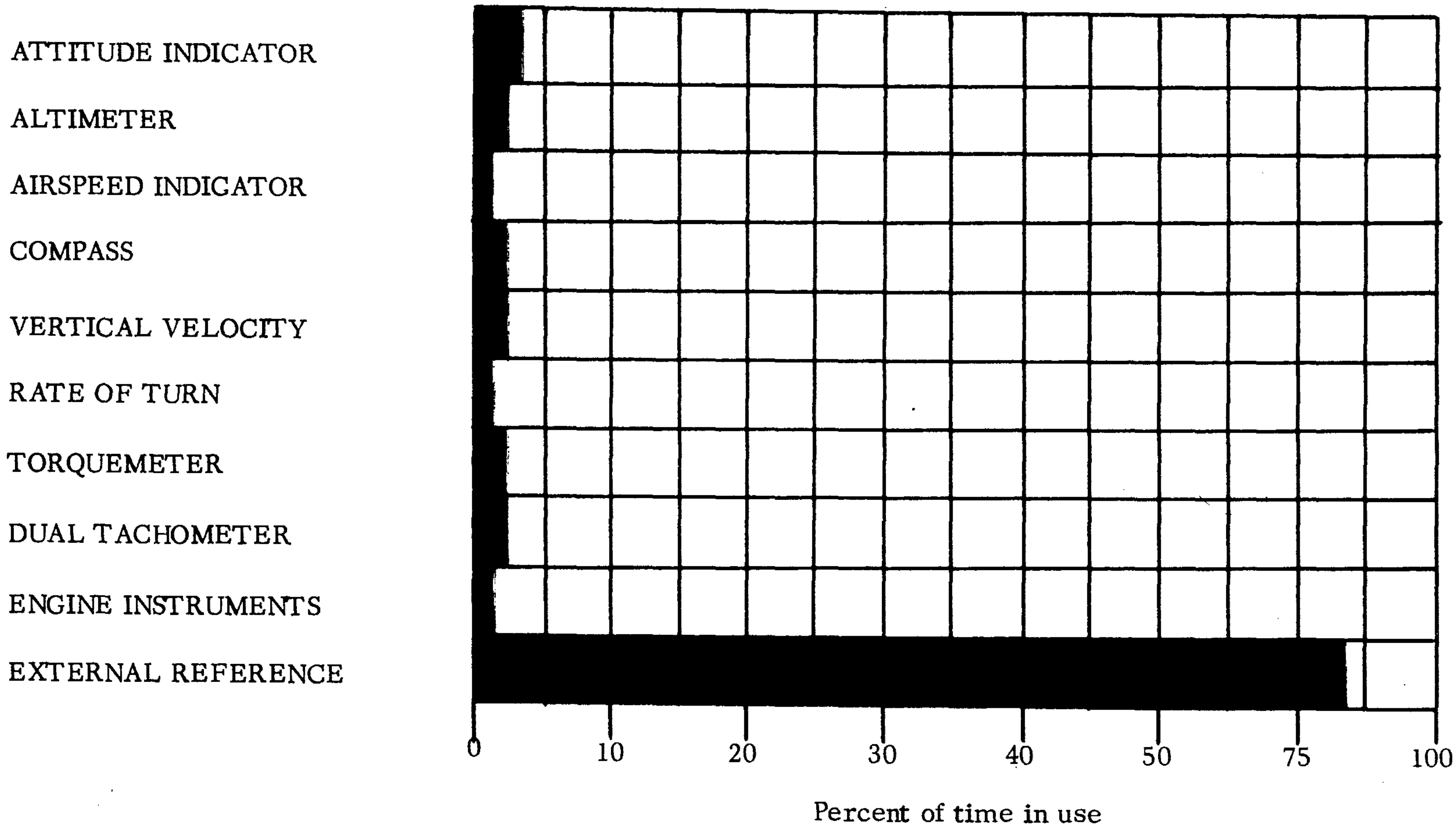

Fig. 1B. SPOT HOVER IGE

TIME-BASED USE ANALYSIS

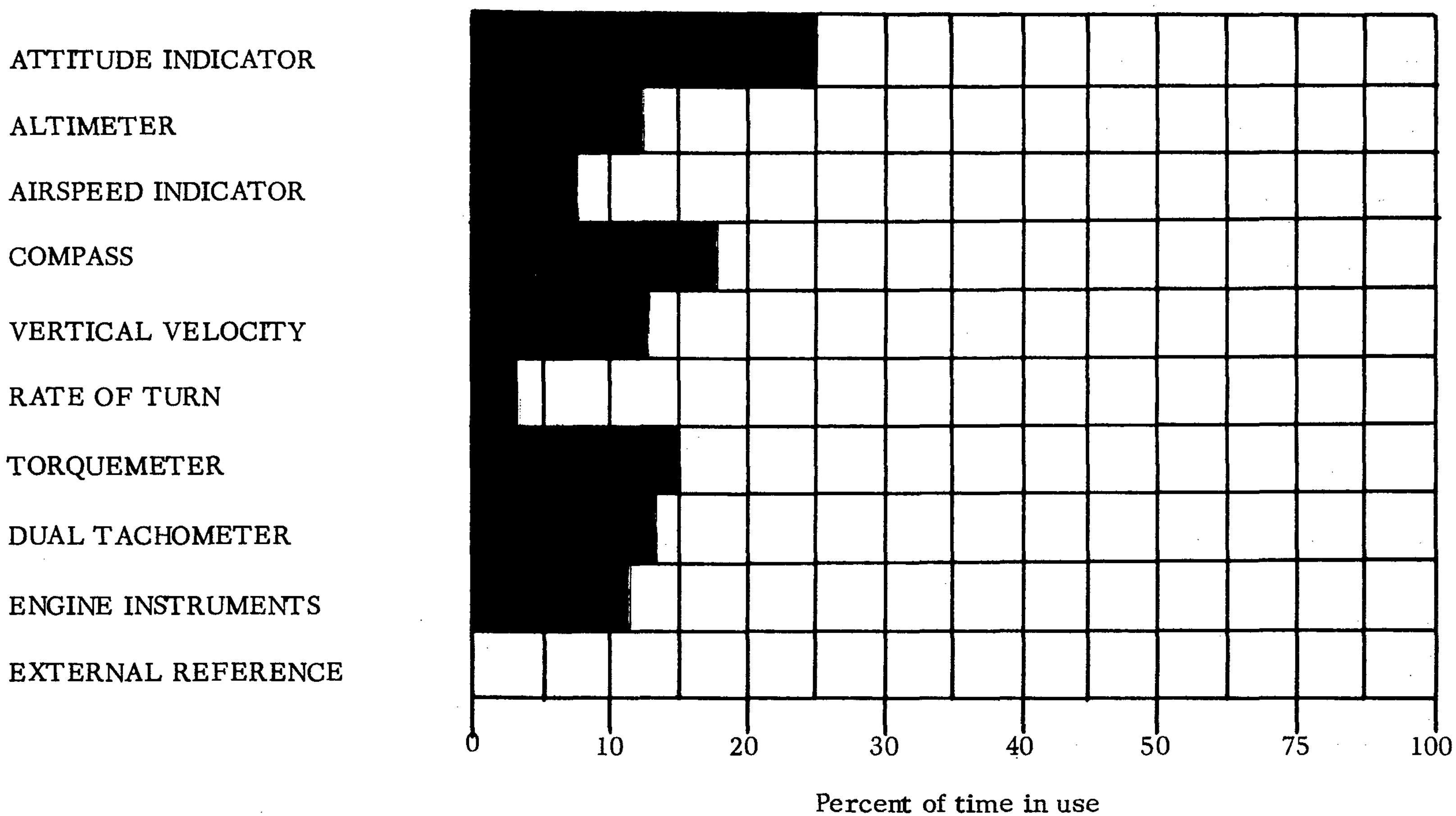

Fig. 2B. SPOT HOVER IGE (IFR)

TIME-BASED USE ANALYSIS

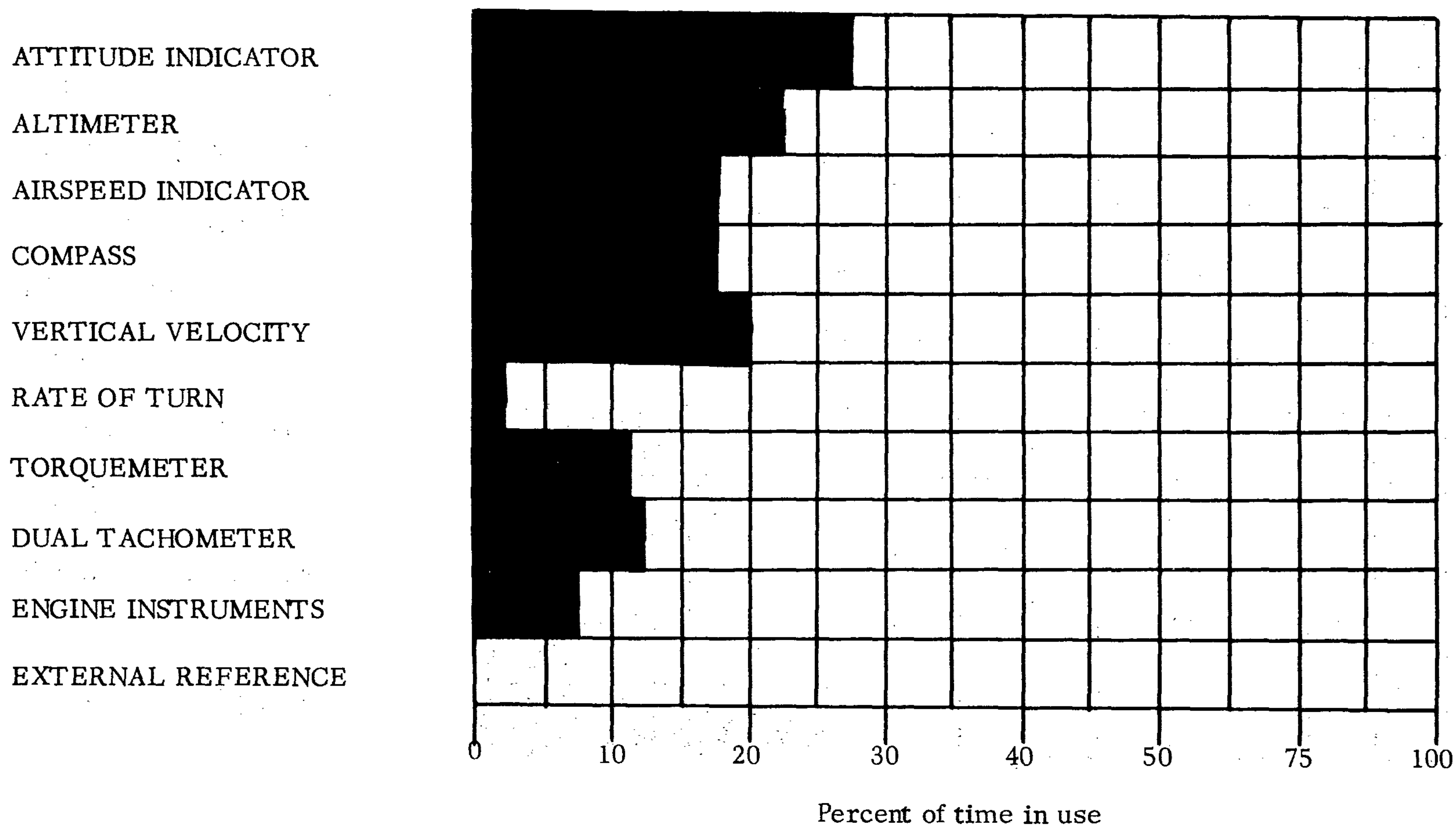

Fig. 3B. SPOT HOVER OGE

TIME-BASED USE ANALYSIS

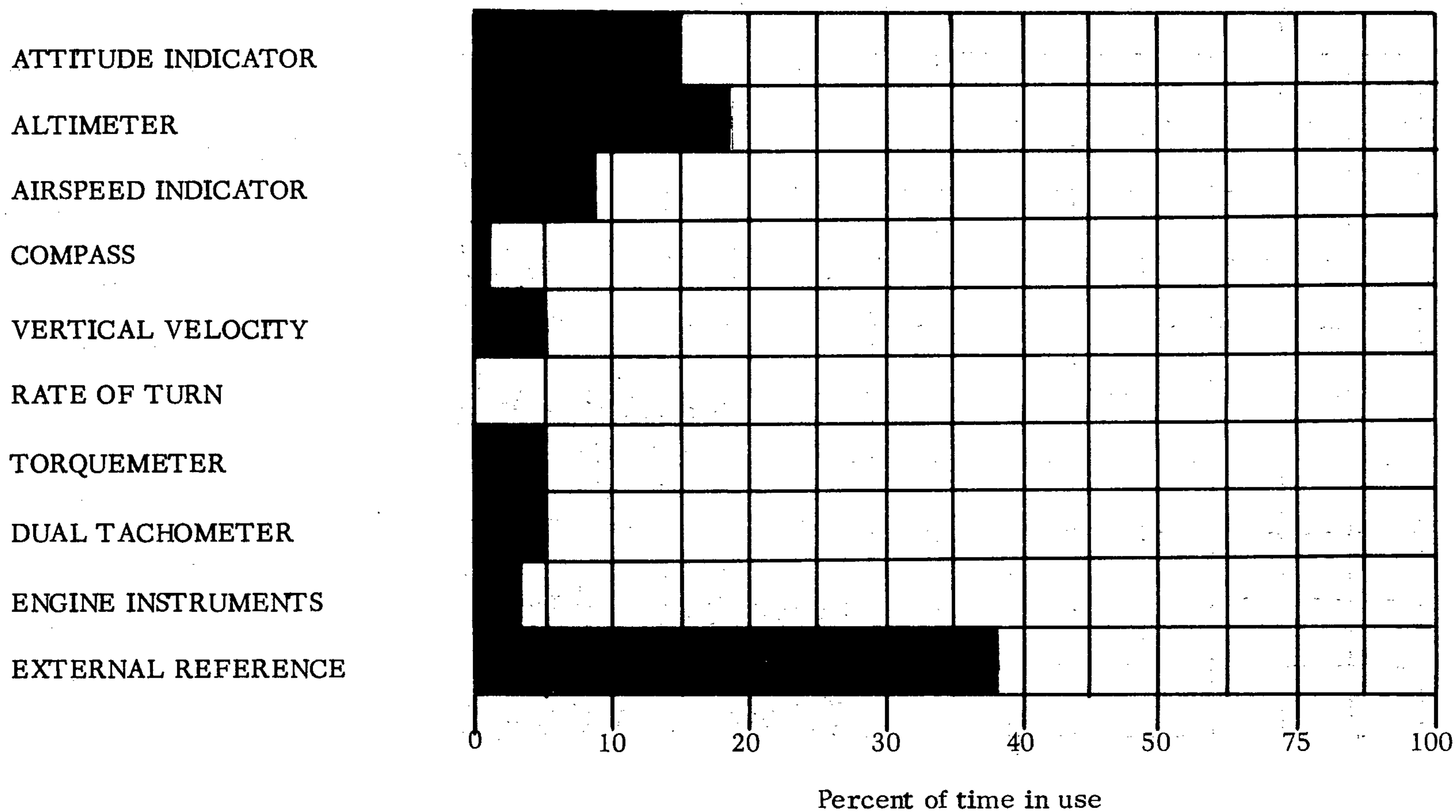

Fig. 4B. 360° HOVERING TURN OGE

TIME-BASED USE ANALYSIS

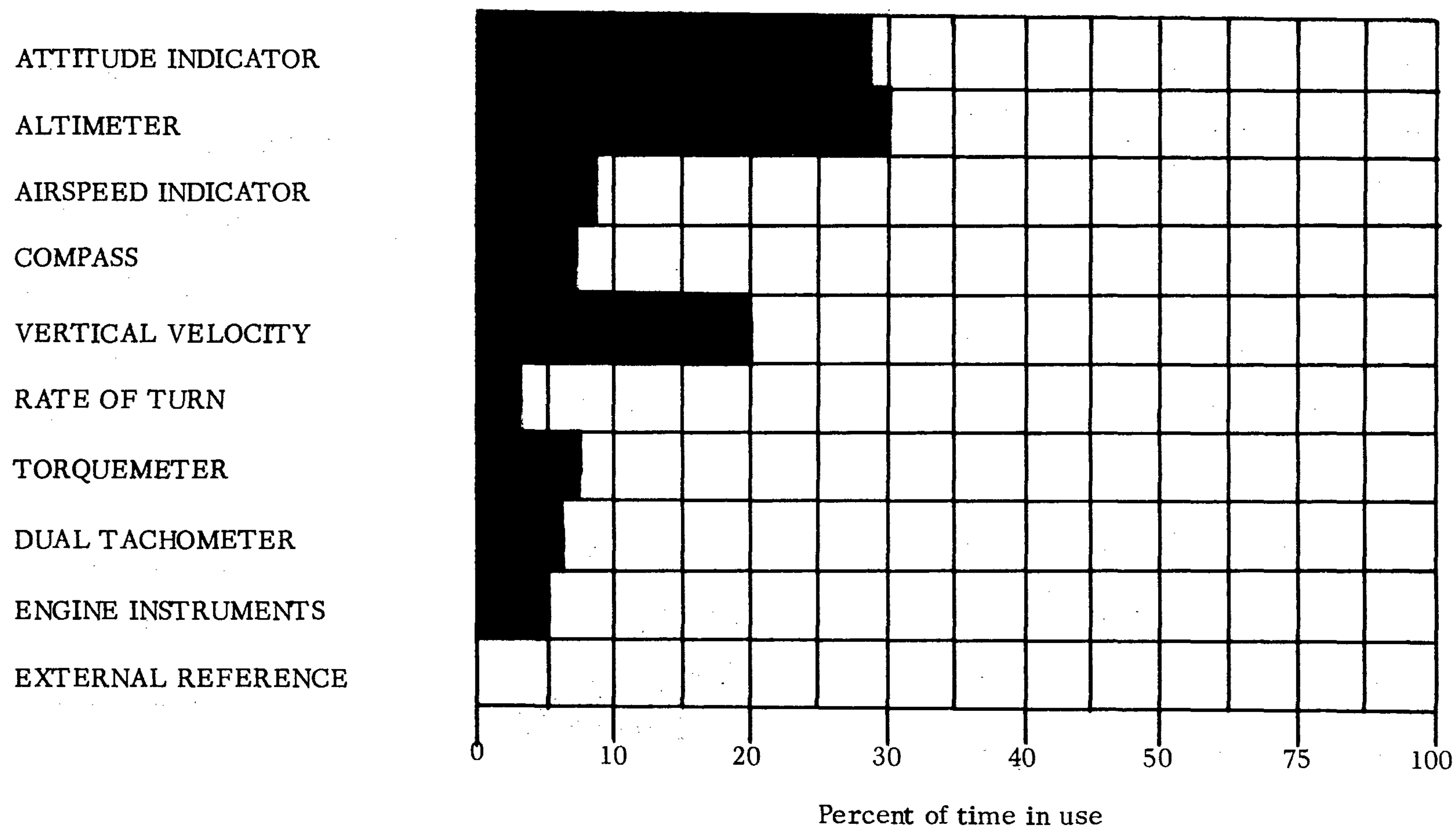

Fig. 5B. VERTICAL CLIMB

TIME-BASED USE ANALYSIS

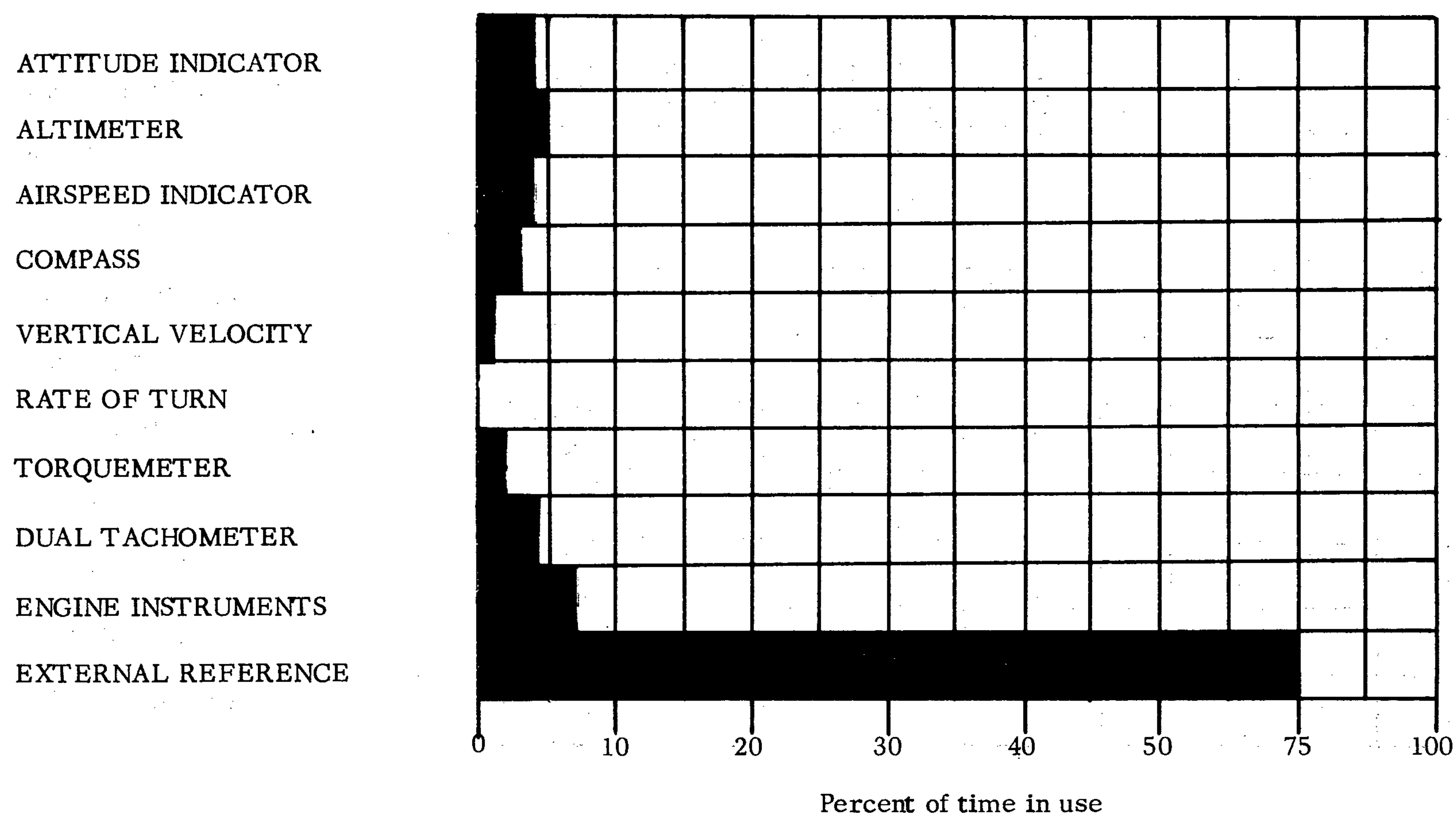

Fig. 6B. VERTICAL DESCENT

TIME-BASED USE ANALYSIS

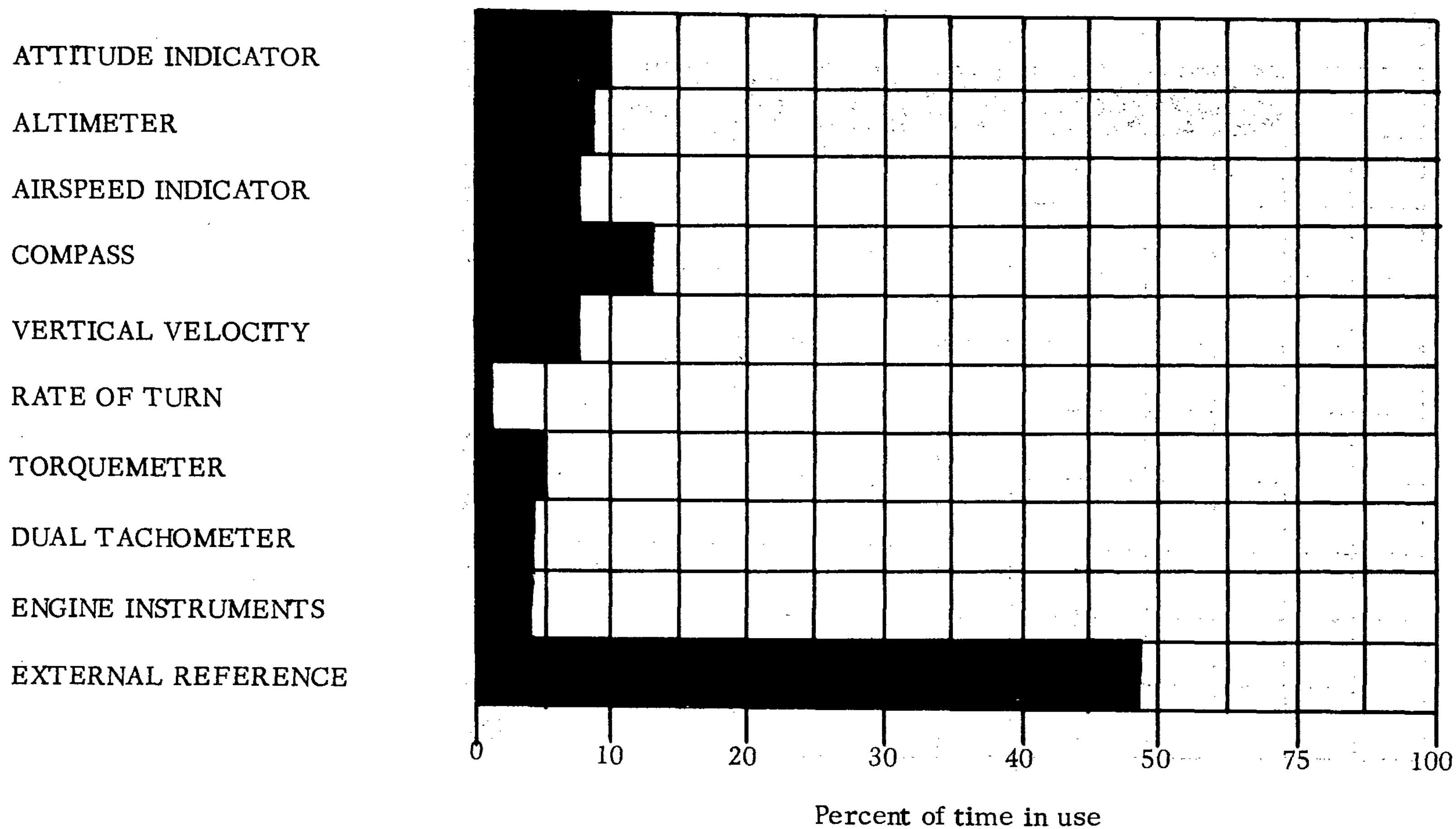

Fig. 7B. CRUISE, 60K, VISUAL

TIME-BASED USE ANALYSIS

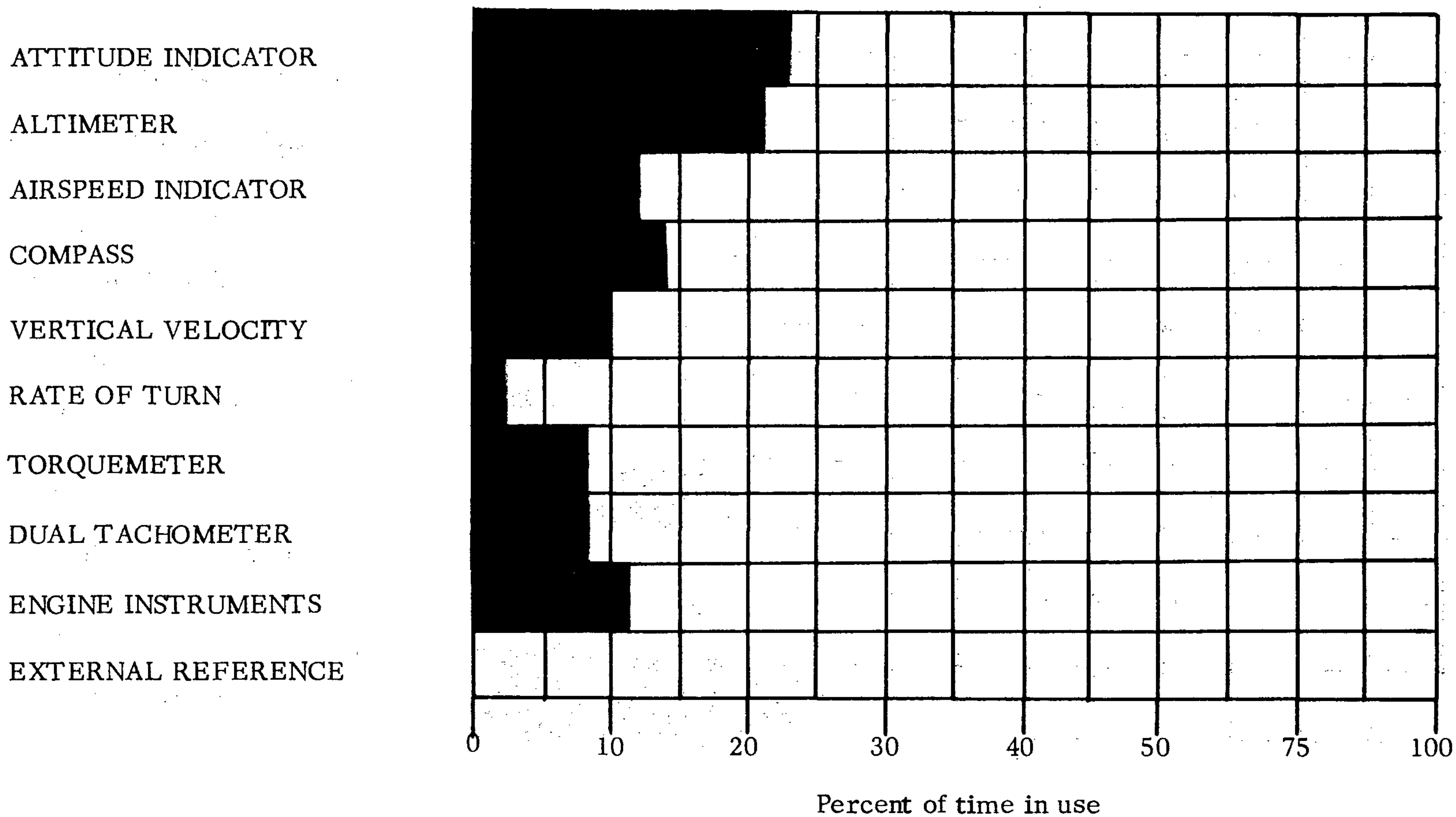

Fig. 8B. CRUISE, 60K, INSTRUMENTS

TIME-BASED USE ANALYSIS

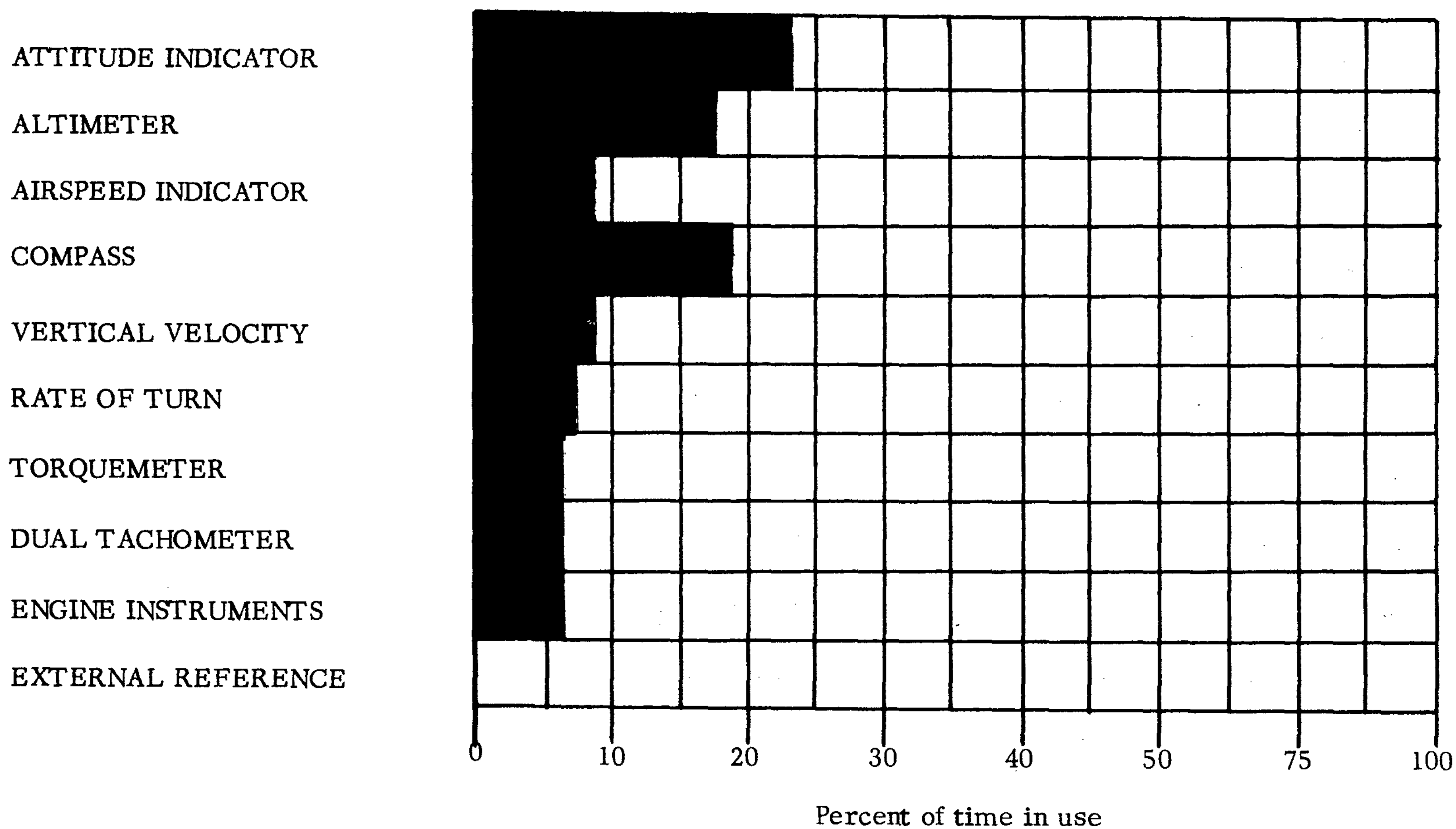

Fig. 9B. STANDARD RATE TURN, 60K

TIME-BASED USE ANALYSIS

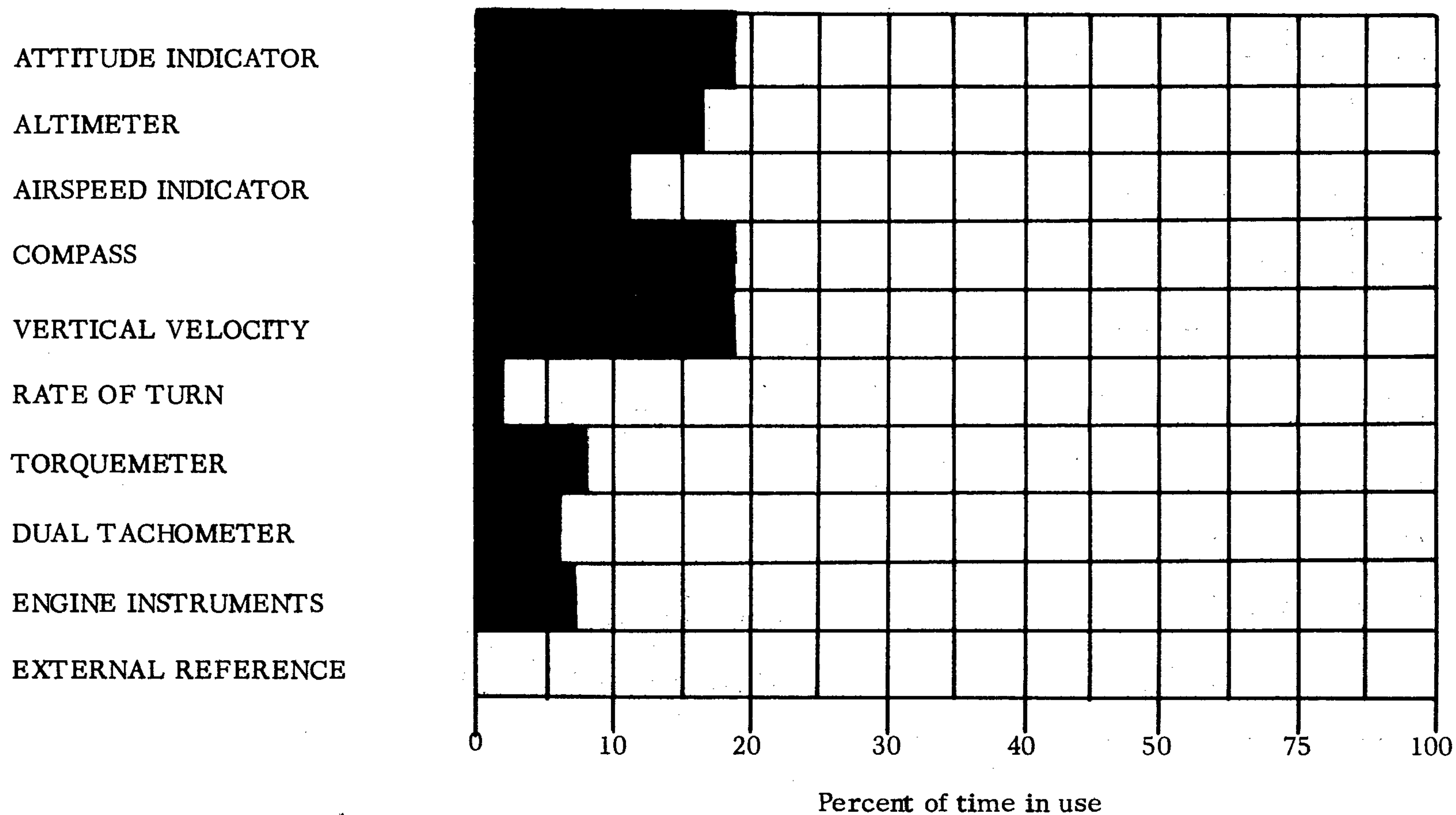

Fig. 10B. CLIMB, 60K, 500 FPM

TIME-BASED USE ANALYSIS

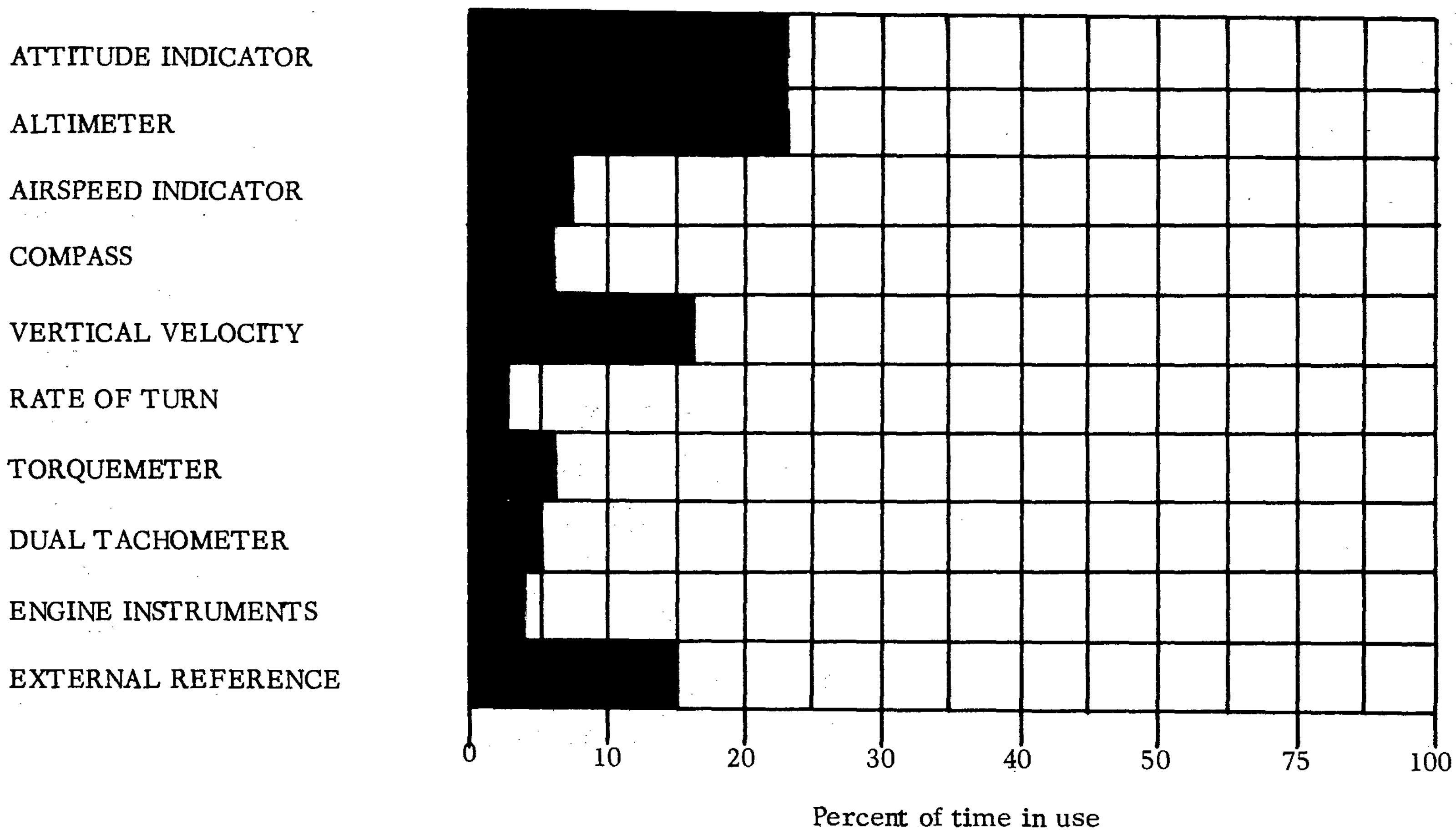

Fig. 11B. CLIMB FROM HOVER

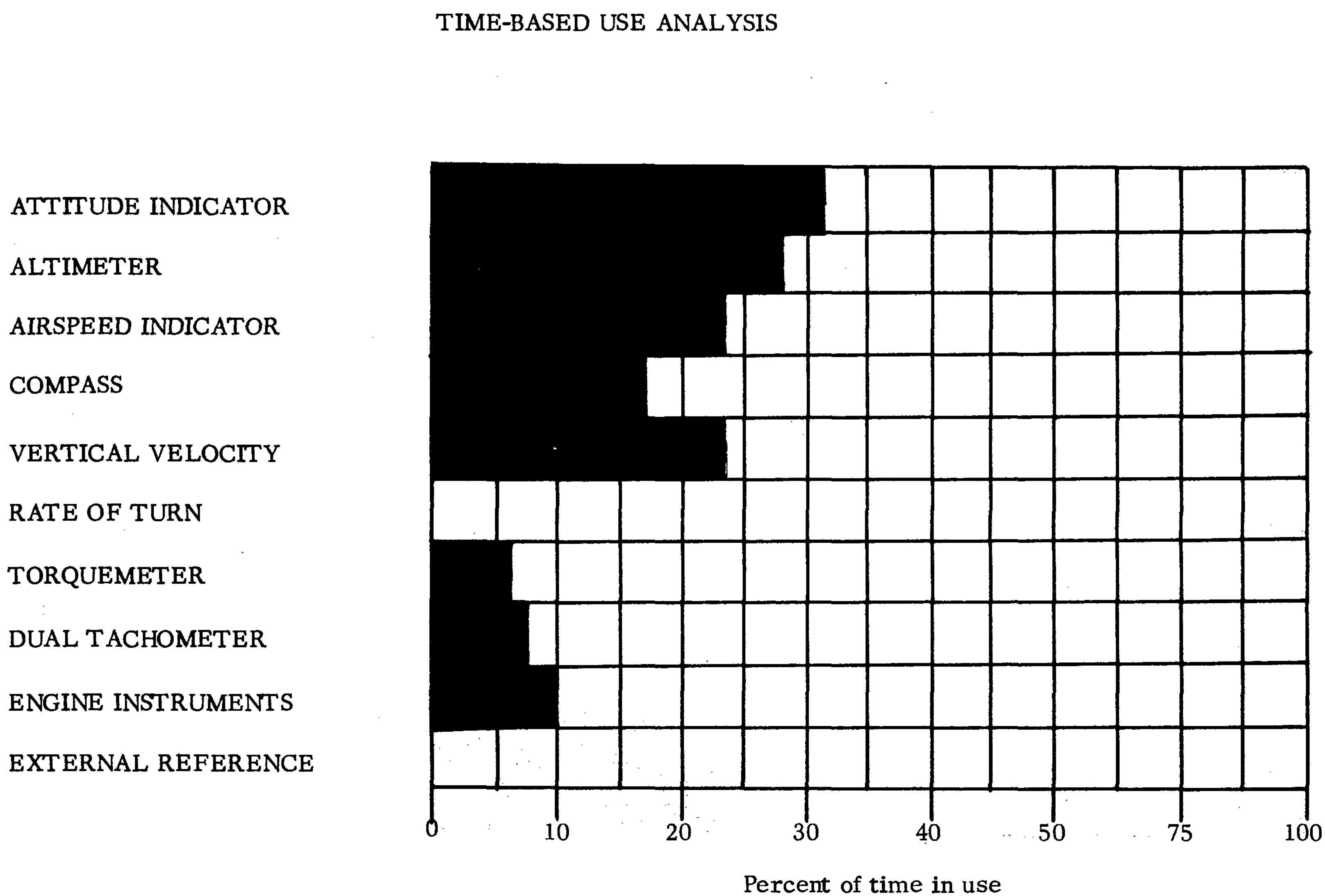

Fig. 12B. INITIAL DESCENT TO 500 FEET (APPROACH), 60K

TIME-BASED USE ANALYSIS

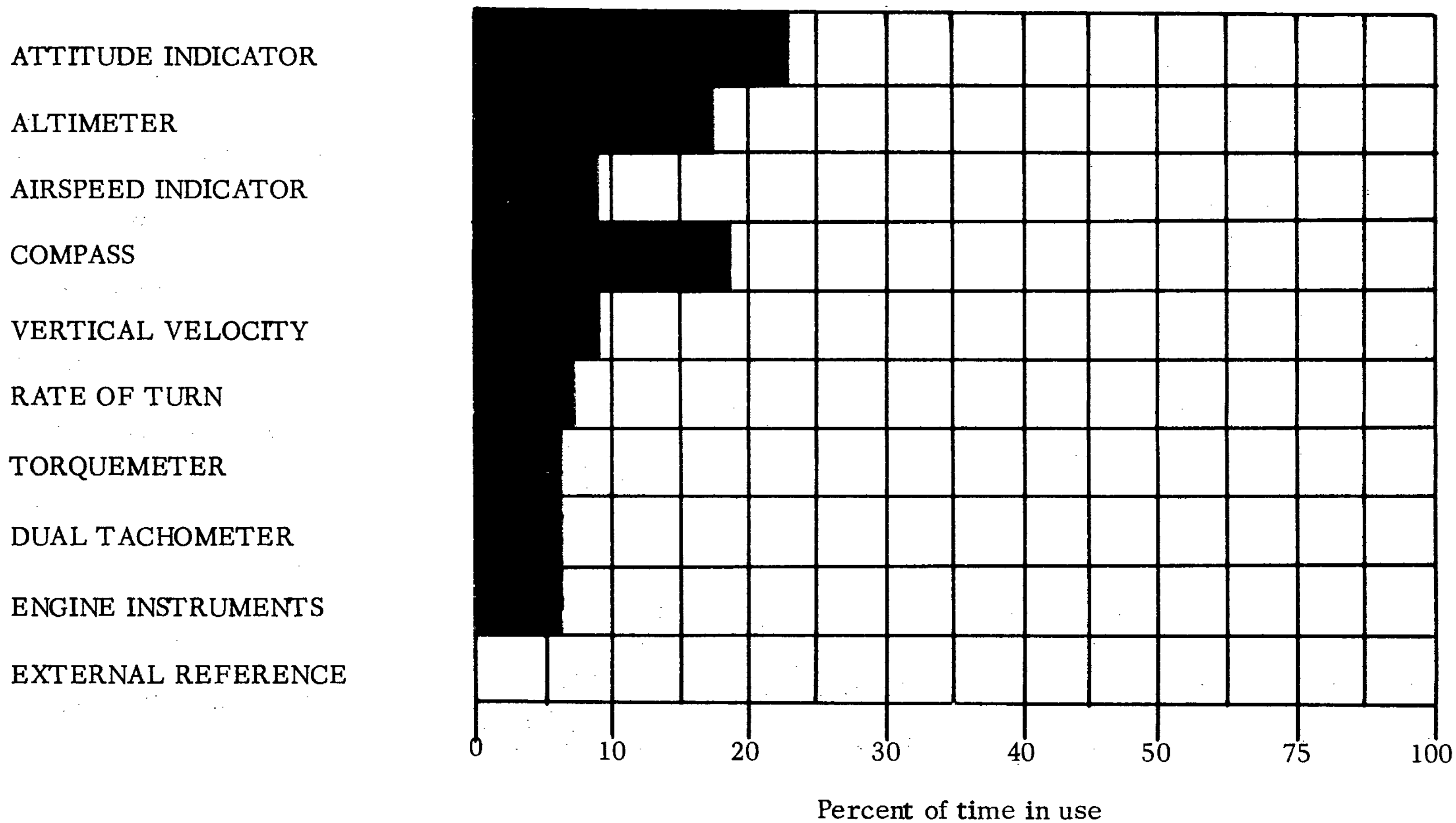

Fig. 13B. REVERSE DIRECTION OF FLIGHT, 60K

TIME-BASED USE ANALYSIS

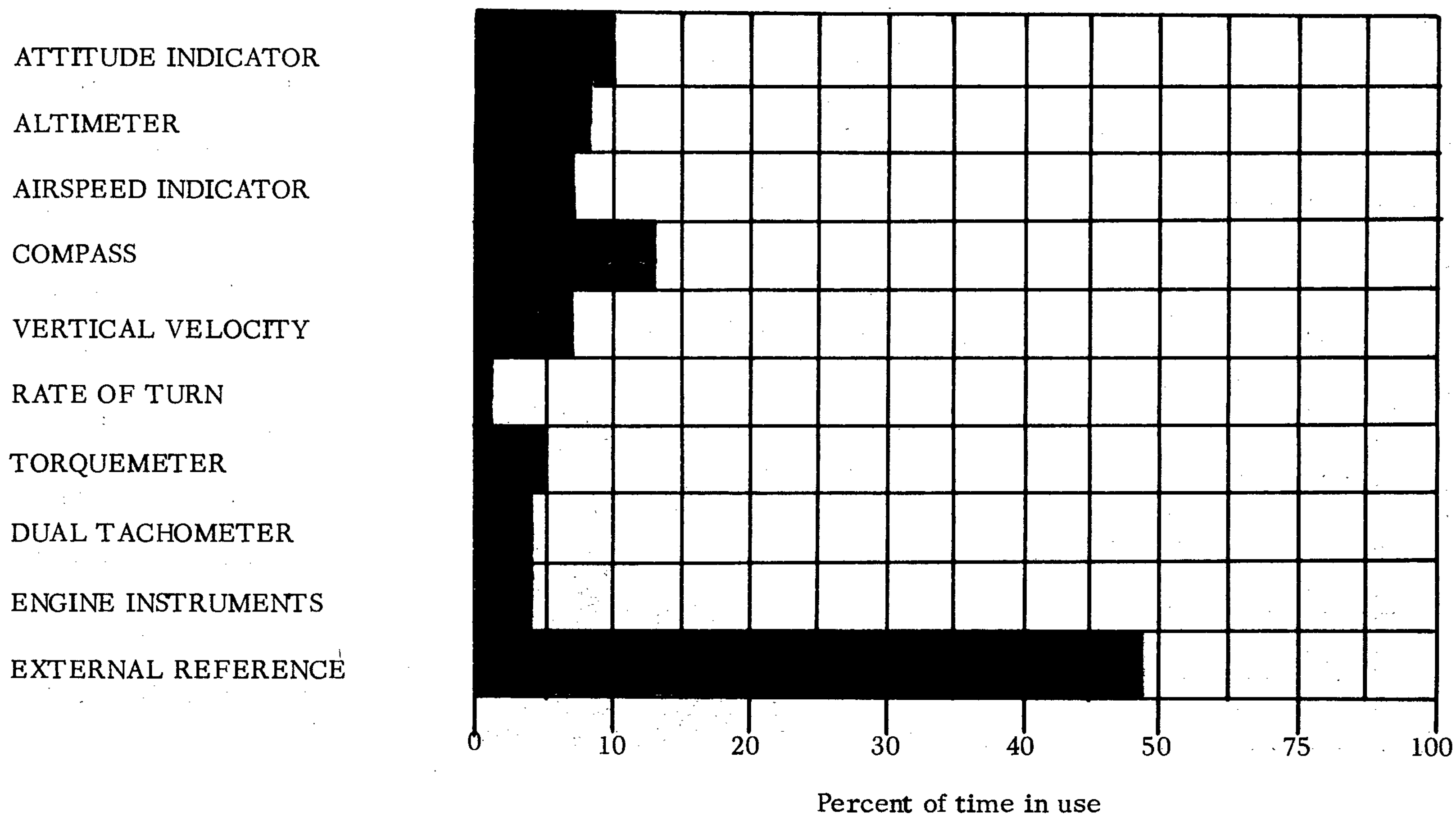

Fig. 14B. CRUISE, 100K, VISUAL

TIME-BASED USE ANALYSIS

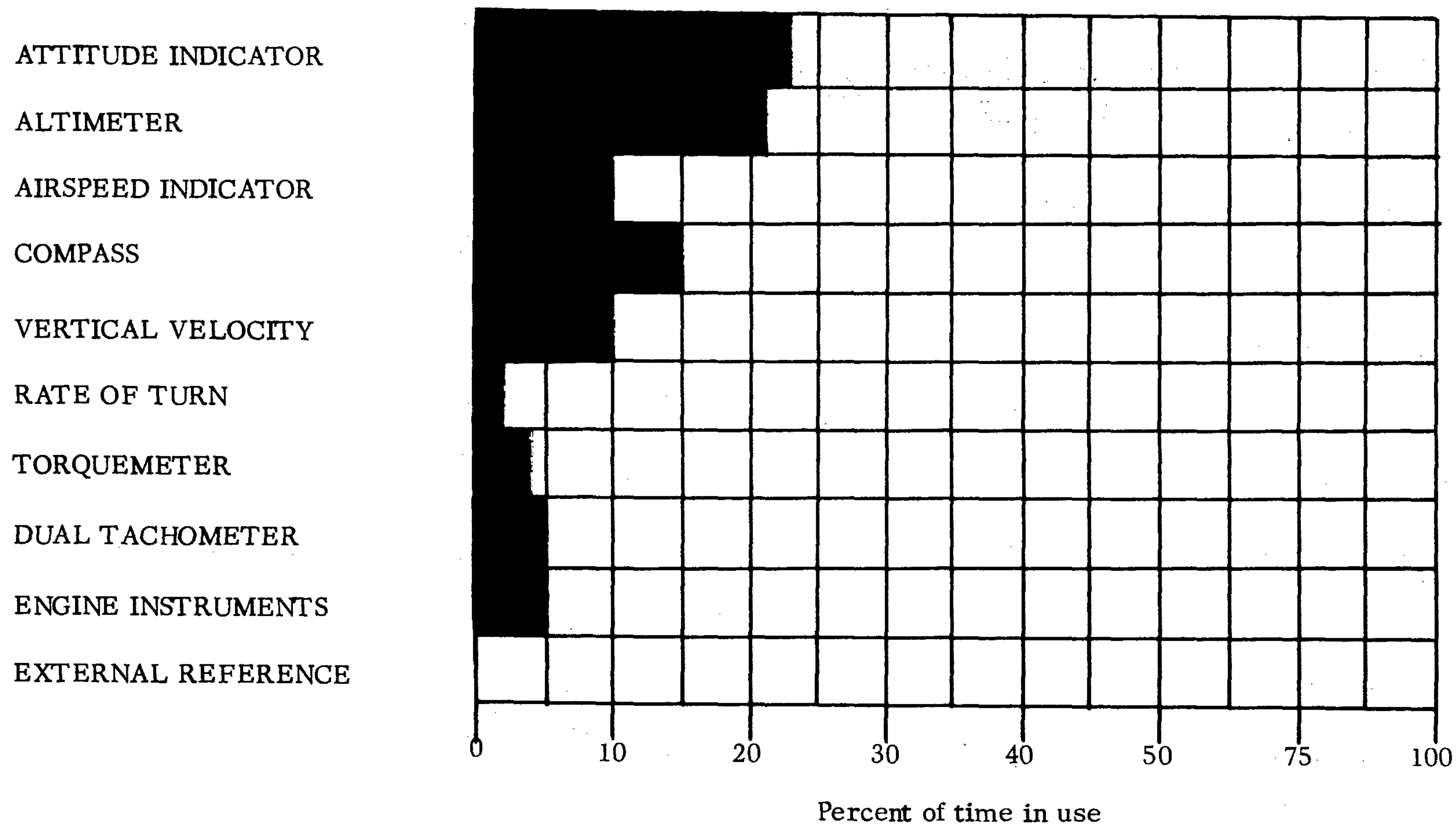

Fig. 15B. CRUISE, 100K, INSTRUMENTS

TIME-BASED USE ANALYSIS

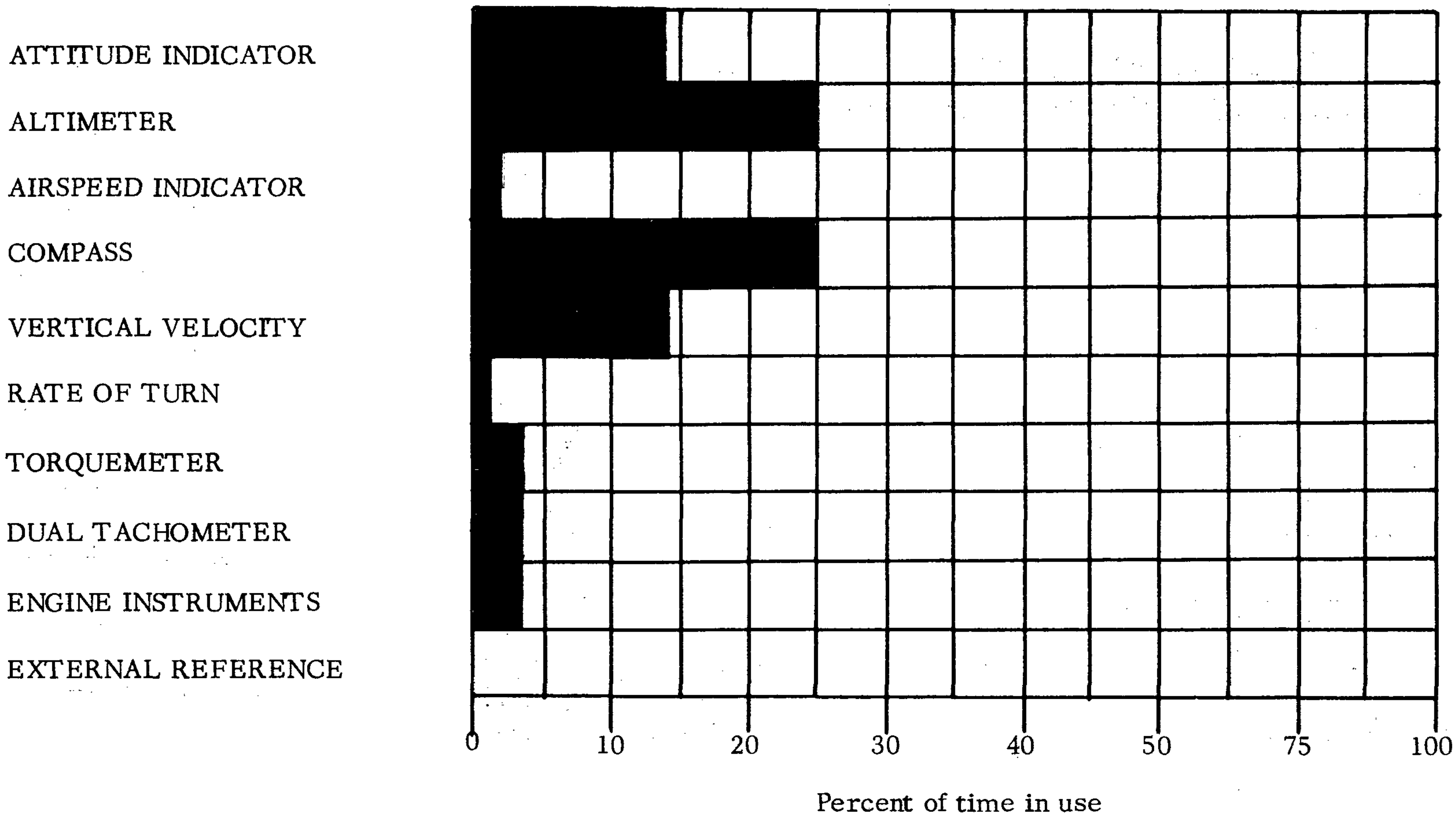

Fig. 16B. STANDARD RATE TURN, 100K

TIME-BASED USE ANALYSIS

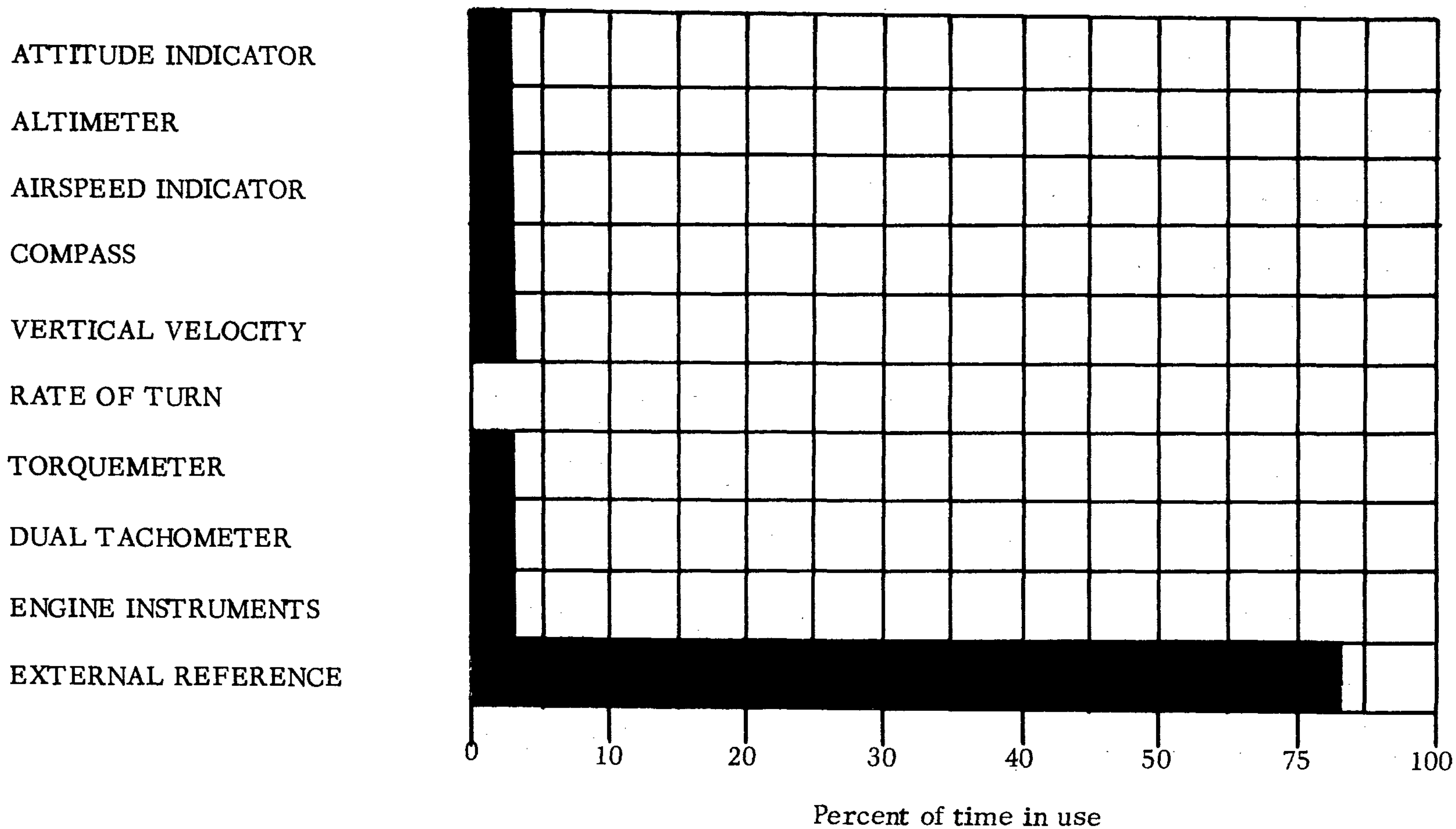

Fig. 17B. TERRAIN FOLLOWING, 100K

TIME-BASED USE ANALYSIS

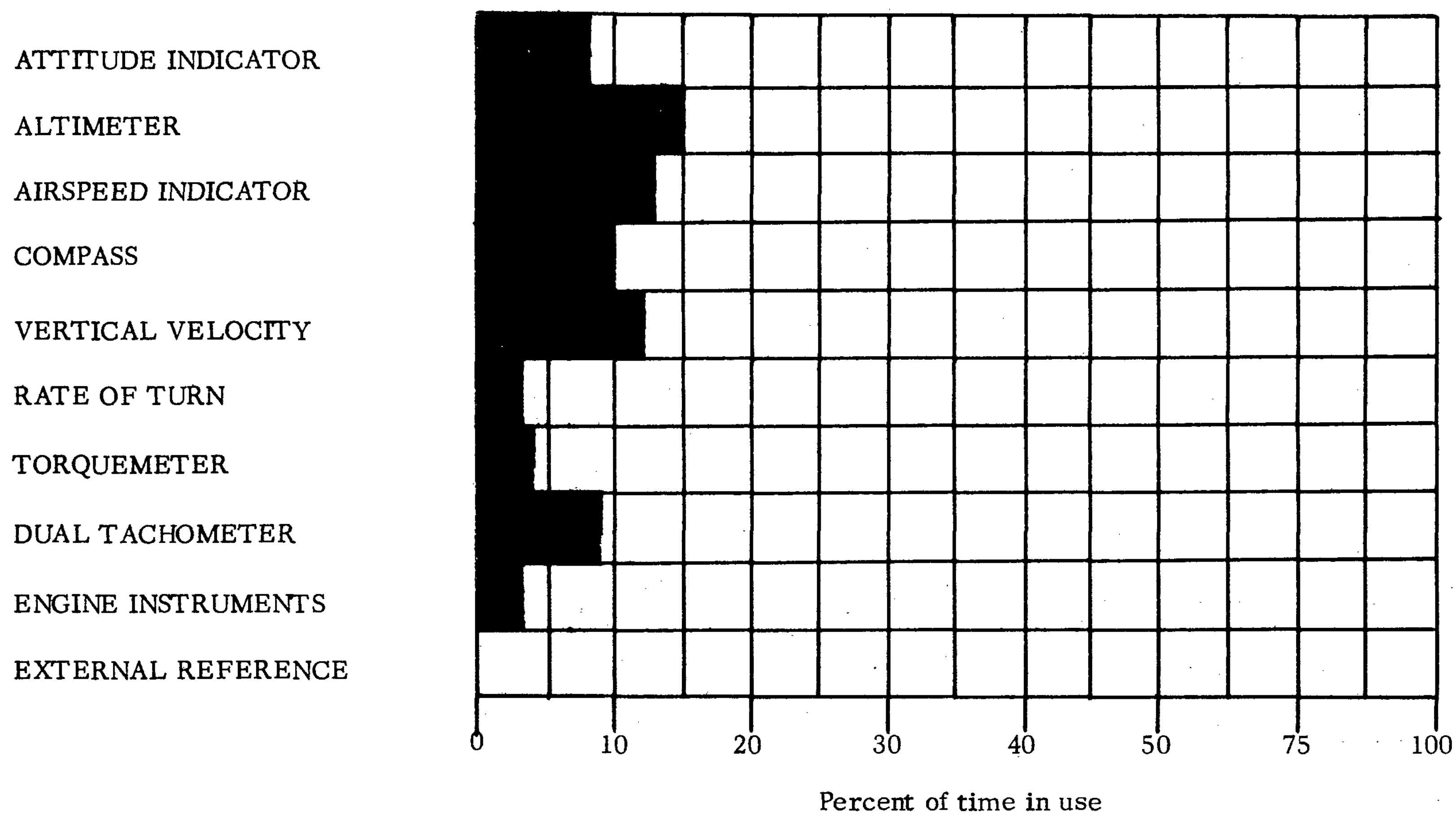

Fig. 18B. CLIMB, 100K, 500 FPM

TIME-BASED USE ANALYSIS

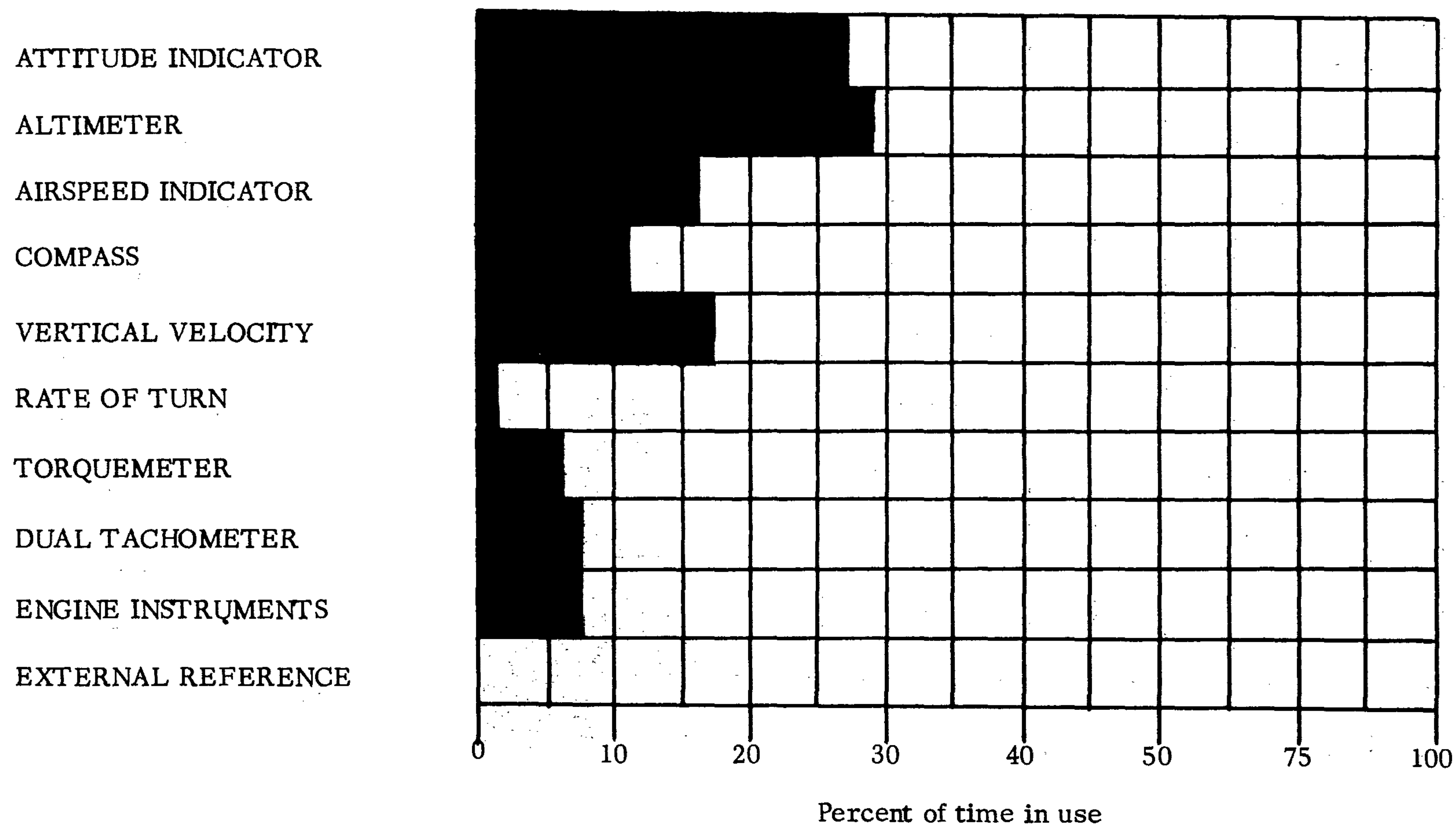

Fig. 19B. DESCENT, 100K, 500 FPM

TIME-BASED USE ANALYSIS

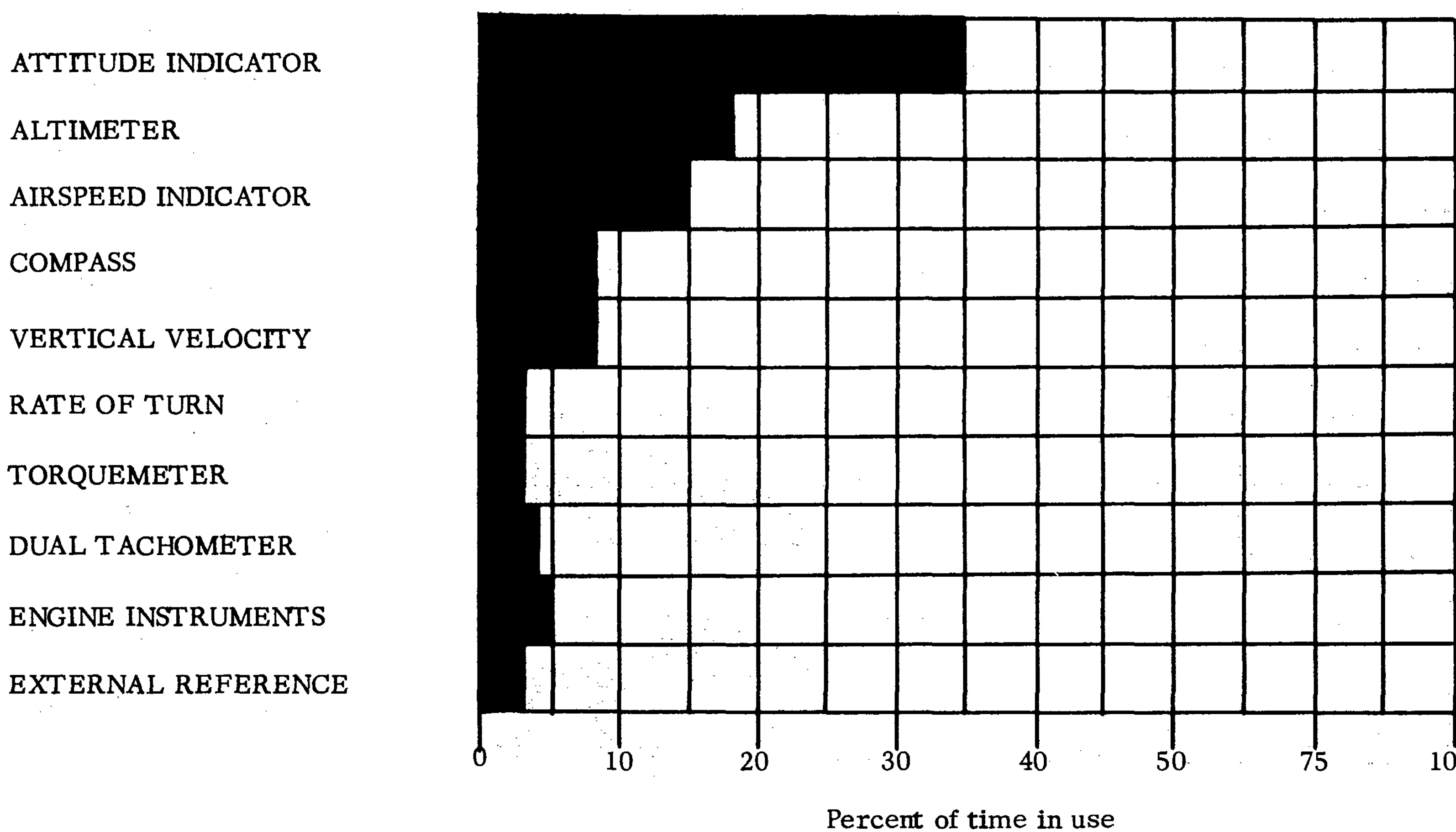

Fig. 20B. 180° DESCENDING TURN, 100K

TIME-BASED USE ANALYSIS

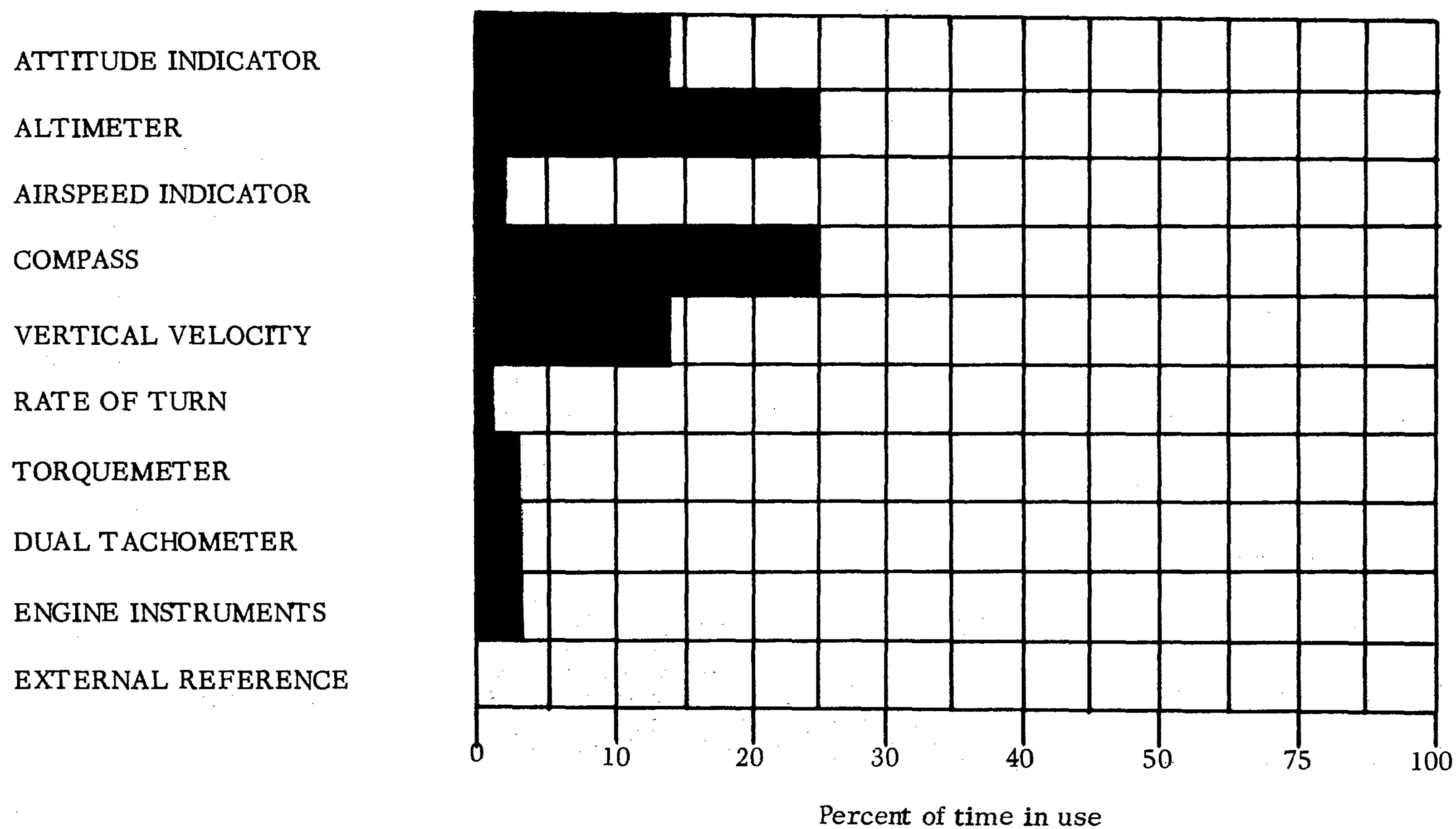

Fig. 21B. REVERSE DIRECTION OF FLIGHT, 100K

APPENDIX C

USE OF THE EMC-2 EYE-MOVEMENT CAMERA

The techniques presented in this section were developed by the author and Mr. Mark J. Monahan. The EMC-2 camera used in this experiment was on loan from U. S. Air Force, AMRL, MRHR, Wright-Patterson Air Force Base, Ohio. This instrument was furnished with a medium and a large APH-6A Air Force flight helmet adapted for the camera system rather than the Guardian notorcycle helmet recommended by the manufacturer (The Westgate Laboratory, Inc., 506 S. High St., Yellow Springs, Ohio). Figure 1C shows the system as used in the initial stages of this study.

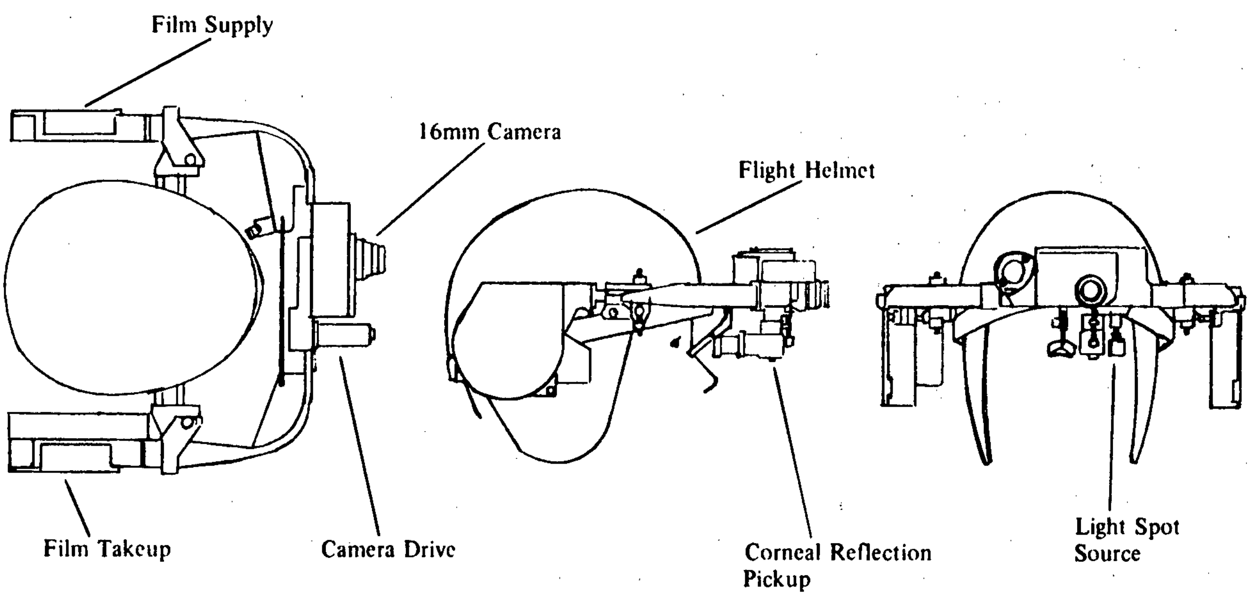

Fig. 1C. EYE MOVEMENT CAMERA SYSTEM

The following description of the system was provided by the manufacturer:

WESTGATE EYE MOVEMENT CAMERA

The model EMC-2 Camera is a light-weight, completely self-contained, head mounted, 16mm motion picture data recording system for research, training and diagnostic study of eye fixation and scanning characteristics.

As the wearer observes a scene, the camera accurately records the points of instantaneous eye fixation. Analysis of the projected film makes it possible to correlate eye movements with various stimuli, and with concurrent measurements of other responses.

In industry and military applications the camera serves as a tool for vigilance studies, training programs, human engineering and product development. Human reactions to real traffic problems, textual materials, packaging, advertising, and color patterns can be accurately recorded and analyzed. In medicine the camera can be a tool for diagnostic study of brain damage and the effects of drugs. It also provides a means for recording reading and scene scanning defects in individuals. Complete portability of the Eye Movement Camera permits its use in both field and laboratory -- practically any place where it is necessary to study eye movement characteristics. This unique system is currently in use by the armed forces, space research laboratories, and leading research organizations.

Principle of Operation

The camera is fixed to a helmet worn on the subject's head. As the camera photographs the subject's field of view, or primary image, a secondary image is superimposed on the film in the form of a small white dot. In each frame the dot indicates the exact point of eye fixation at the instant of exposure. The secondary image is created by the corneal reflection of a pinpoint light trained on the subject's left eye. The reflected spot is imaged on the back of the film and superimposed on the primary image. At the film plane, the reflected spot can be as small as 0.13" in diameter. Larger spot sizes can be achieved by changing the aperature mask.

The shape of the cornea causes the position of the reflected light to change with eye movement, accurately indicating the point of instantaneous eye fixation.

Camera System

The electrically operated camera system is in the form of a horseshoe, with film supply and take-up spools located on either side of the head. The spools hold up to 125 feet of film. Speed is adjustable to 4, 8, or 16 frames per second.

Speeds to 100 frames per second can be provided. Recording time is 21 minutes at 4 frames per second.

The system is easily controlled by the subject or investigator with a hand-held control box, containing switches to regulate power, camera speeds, and light source intensity. Power is supplied either by a battery strapped to the subject's waist or by an external source.

For convenience in conducting experiments, a switch closure with each frame is provided to synchronize the camera data with voice recordings, oscillographs, and other forms of recorded information.

It is possible to determine which instrument is being viewed in an aircraft cockpit, or which sign or vehicle is the point of attention in a driver study. Special lenses provide even greater detail showing the instrument portion, or particular letter being viewed in a line of text.

Data can be reduced rapidly with a 16mm projector of editing viewer.

Calibration and Adjustment

The camera and helmet can be adjusted laterally, longitudinally, and rotationally to fit each subject's anthropometric requirements. The nose steady-rest is also adjustable. If the camera and helmet must be removed and replaced often during an experiment, or if excessive head motion may be encountered, the optional bite bare is necessary in order to maintain calibration.

A Calibration Viewer, VC-1, attaches to the camera in place of the primary scene lens to permit adjustment and calibration of image alignments for the entire field of view.

An Alignment Check Viewer provides a means of retaining the subject's basic adjustments if the helmet must be removed. When the helmet is replaced, the subject may rapidly reproduce the previous position.

When telephoto lenses are used for greater detail and accuracy, the adjustable bite bar is recommended.

Calibration Stand

The Calibration Stand, an optional accessory, provides a practical and safe means for supporting the camera and helmet for film loading and unloading, initial calibration, training, storage or test purposes.

SPECIFICATIONS

Camera

Custom designed, electrically driven, 16mm motion picture camera. Frame rates adjustable to 4, 8, and 16 frames per second. Rates to 100 frames per second are available on special order. Camera without helmet and film weighs 3.9 pounds.

Film

Capacity of 100 feet standard 16mm film, or 125 feet of Dupont Kronar base film. Maximum recording time 21 minutes at 4 frames per second.

Lens

Five element f/2.2 lens with 10mm focal length. Capable of resolving scene elements separated by less than 1^{o} of arc. Field of view 20^{o} from nominal line of sight. Other lenses, including wide angle, may be used.

Helmet

Camera is normally mounted on a Guardian motorcycle safety helmet. Basic camera is readily adaptable to other commercial and military helmets.

Electrical

Input power 28 volts DC supplied to control box from external source or battery strapped to subject's waist. Current drain is 1.24 amperes.

HEL CALIBRATION PROCEDURES

The accurate calibration of the system is essential for obtaining successful results. For the study a camera-to-panel distance of 24 inches was used. This was representative of the eye-to-panel distances encountered in the aircraft used.

A calibration chart was constructed which consisted of cross-hairs and two square rings: the inner ring was 3.2 inches on a side and the outer ring was six inches on a side. These measurements were determined by calculations using the optical specifications of the camera tempered by a dash of cut-and-fit technique.

This size chart used for calibration effectively covers the maximum recordable scan area of the system. To produce the calibration strips of film which must be in the film gate of the camera for initial calibration, a target was constructed in the same design as the calibration chart with the following dimensions: cross-hair lines were 1/4 inch Black ChartPak, the inner ring was 8.625 inches on a side and made of 1/2 inch Black ChartPak, and the outer ring was 15.75 inches on a side and made of 1/2 inch Black ChartPak. The target background was white poster board and was placed 24 inches from the rear element in the lens system of the camera.

The first step in calibrating this system is to make sure the boresight light from the camera is actually indicating the center of the target. This was done by placing the camera in the calibration stand and centering the boresight light on the center of the target. Several feet of film was then exposed and the picture of the target was checked against the center of the picture frame. Slight adjustments can be made in the boresight light by the use of shims at the mounting points.

Calibrating the system for use required a snug but comfortable fit of the helmet and adjustment of the camera helmet mounts so that there was sufficient movement of the periscope in the vertical direction to accommodate the subject's eye.

Prior to an actual run with the system a calibration leader strip was attached to the film and loaded into the camera. This film was advanced through the camera until all drive sprockets contained film. The lens was then removed and a frame of the calibration strip was stopped and centered in the film gate with the shutter in the open position. The system was then put on the subject. When the helmet was properly donned and the helmet chin strap fastened, the bite bar attachment was adjusted to the subject and the light source was adjusted to project a dot of light on the subject's cornea.

The experimenter now installed the VC-1 Calibration Viewer in the camera in place of the lens so that he might adjust the periscope to provide the proper size light spot reflected from the eye onto the calibration strip of film in the film gate. The instructions furnished with the system cover this step in detail. The subject was then instructed to look at the calibration chart, which was approximately 24 inches in front of him, and to aim his head so that the boresight light coincided with the intersection of the cross-hairs. He was then instructed to fixate on this point while the experimenter checked through the VC-1 to see if the reflected light from the cornea was also in the center of the calibration strip of film; if it was not, the periscope was adjusted to place it there. When this adjustment was accomplished the subject was instructed to look at the lower left corner of the inner sighting ring; if the calibration was correct the dot of light on the calibration strip of film moved to the upper right corner of the inner ring. This step was repeated for all four corners of both of the sighting rings and adjustments made if necessary. When this procedure was completed, the VC-1 was removed and the lens was installed in the camera. The initial calibration of a subject, after the helmet had been fitted, took

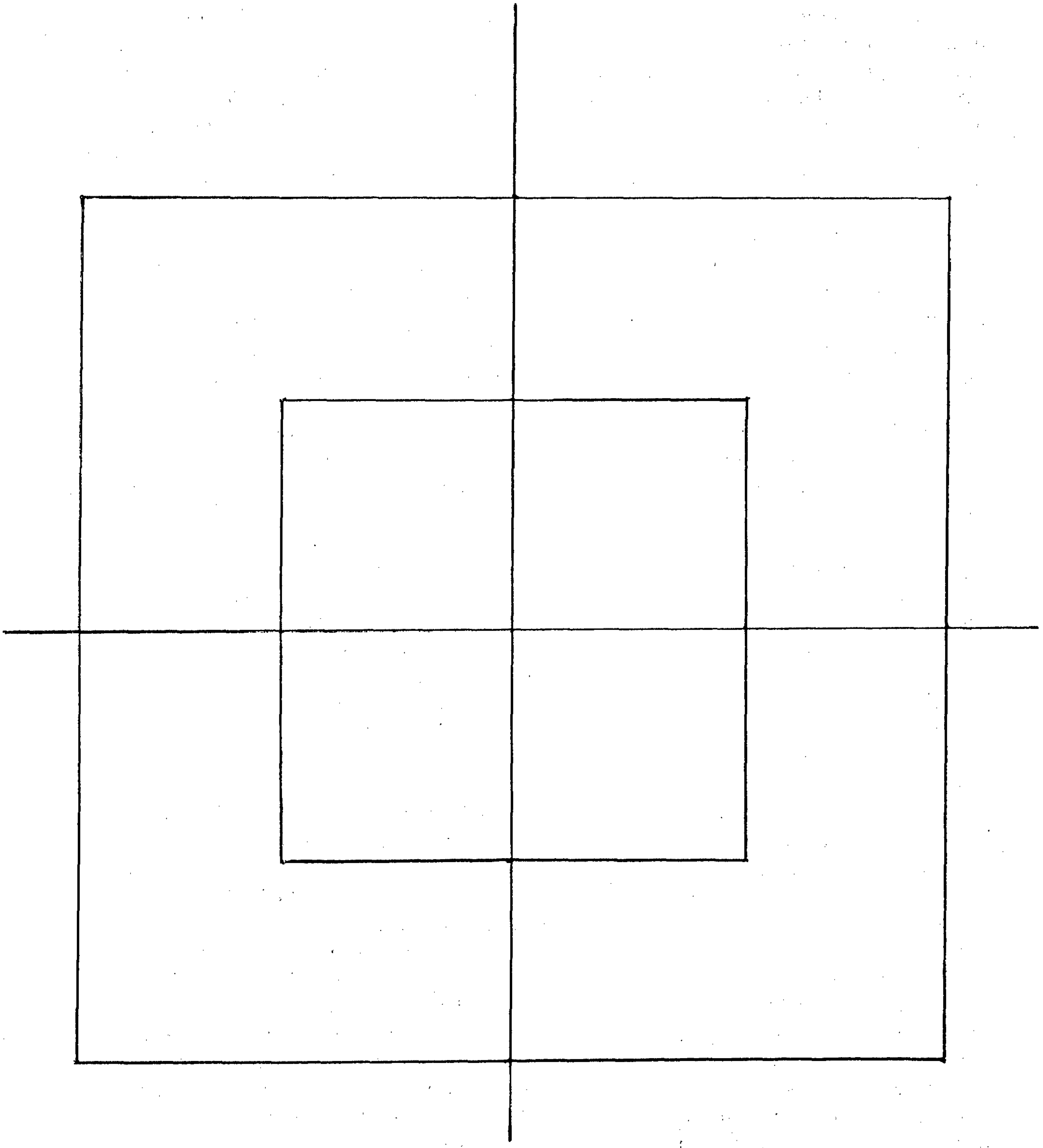

Fig. 2C. EMC-2 CALIBRATION CHART

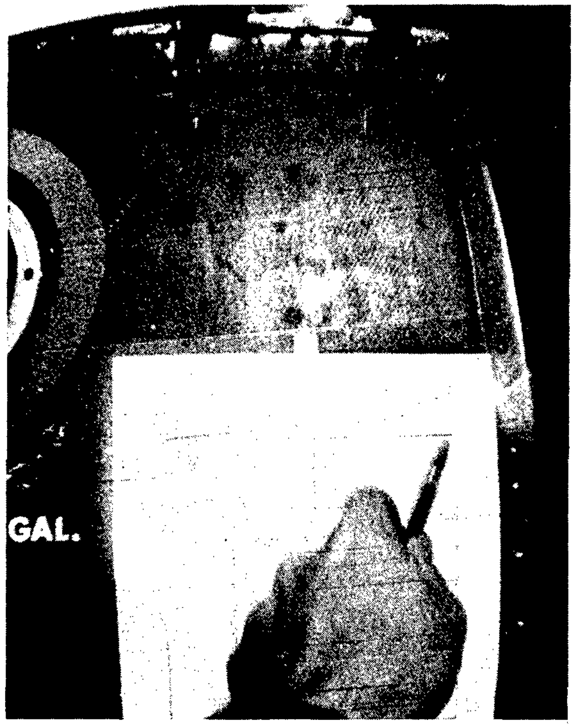

Fig. 3C. EYE FIXATION POINT DURING CALIBRATION

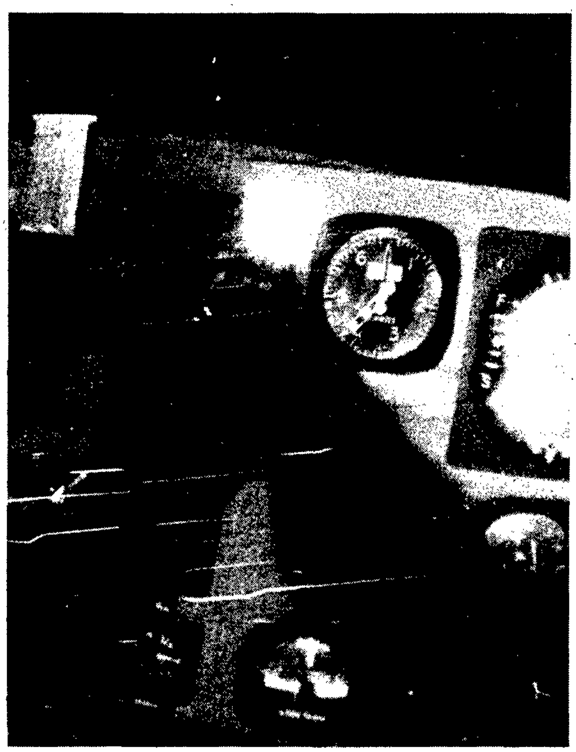

Fig. 4C. EYE FIXATION POINT ON SIMULATOR TORQUEMETER AFTER CALIBRATION

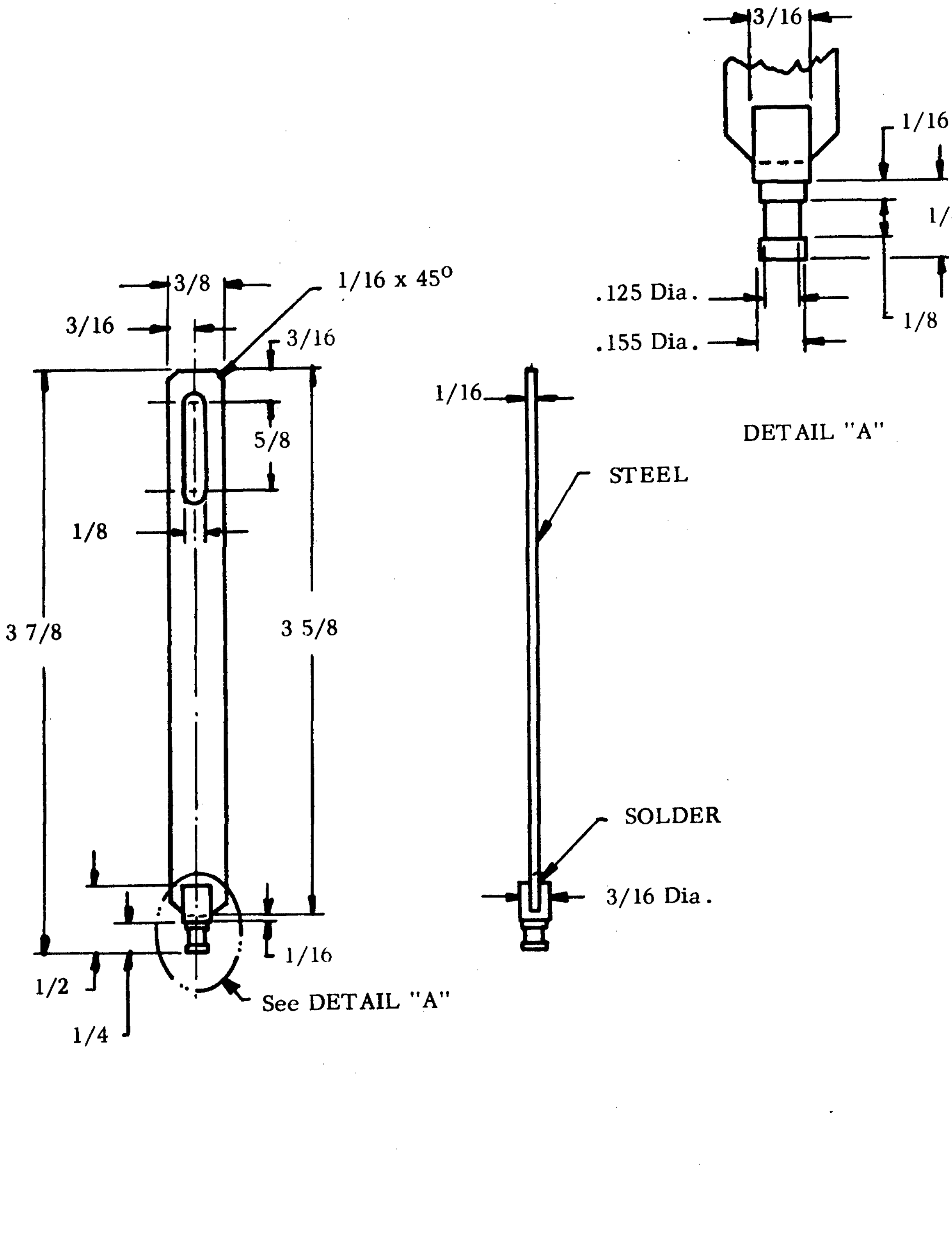

Fig. 5C. PLAN AND ELEVATION VIEW OF BITE BAR BRACKET

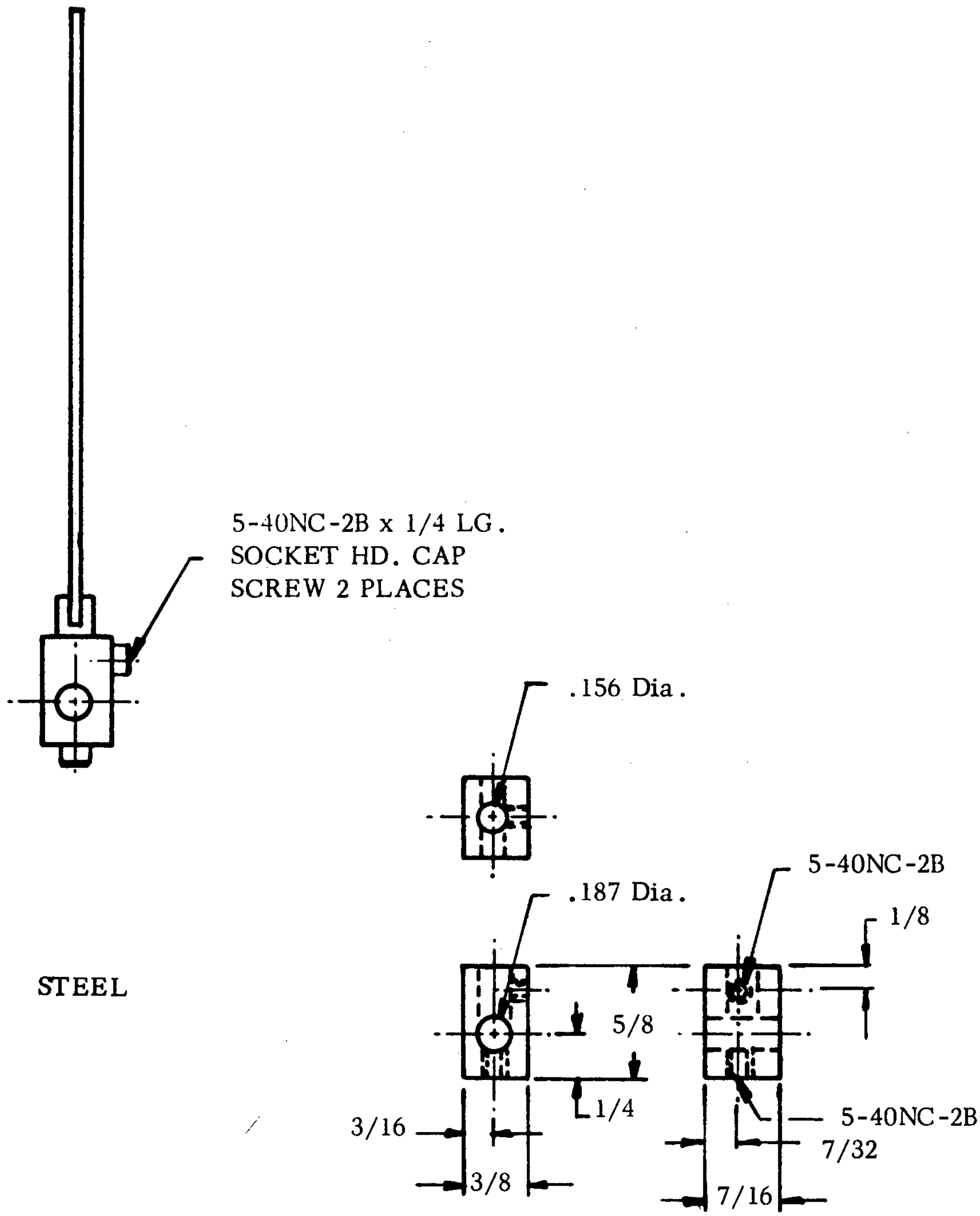

Fig. 6C. BITE BAR BRACKET WITH BLADE HOLDER ATTACHED AND PLAN AND ELEVATION VIEWS OF BITE BAR BLADE HOLDER

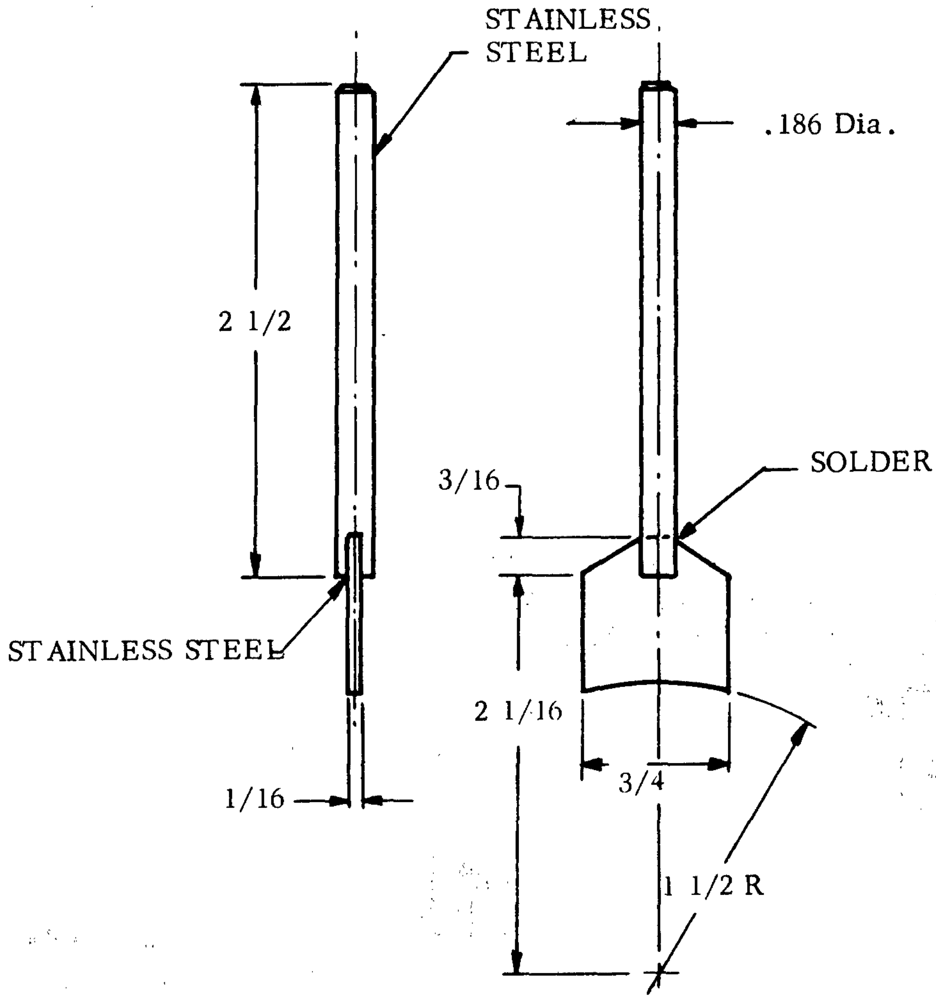

Fig. 7C. PLAN AND ELEVATION VIEW OF BITE BAR BLADE

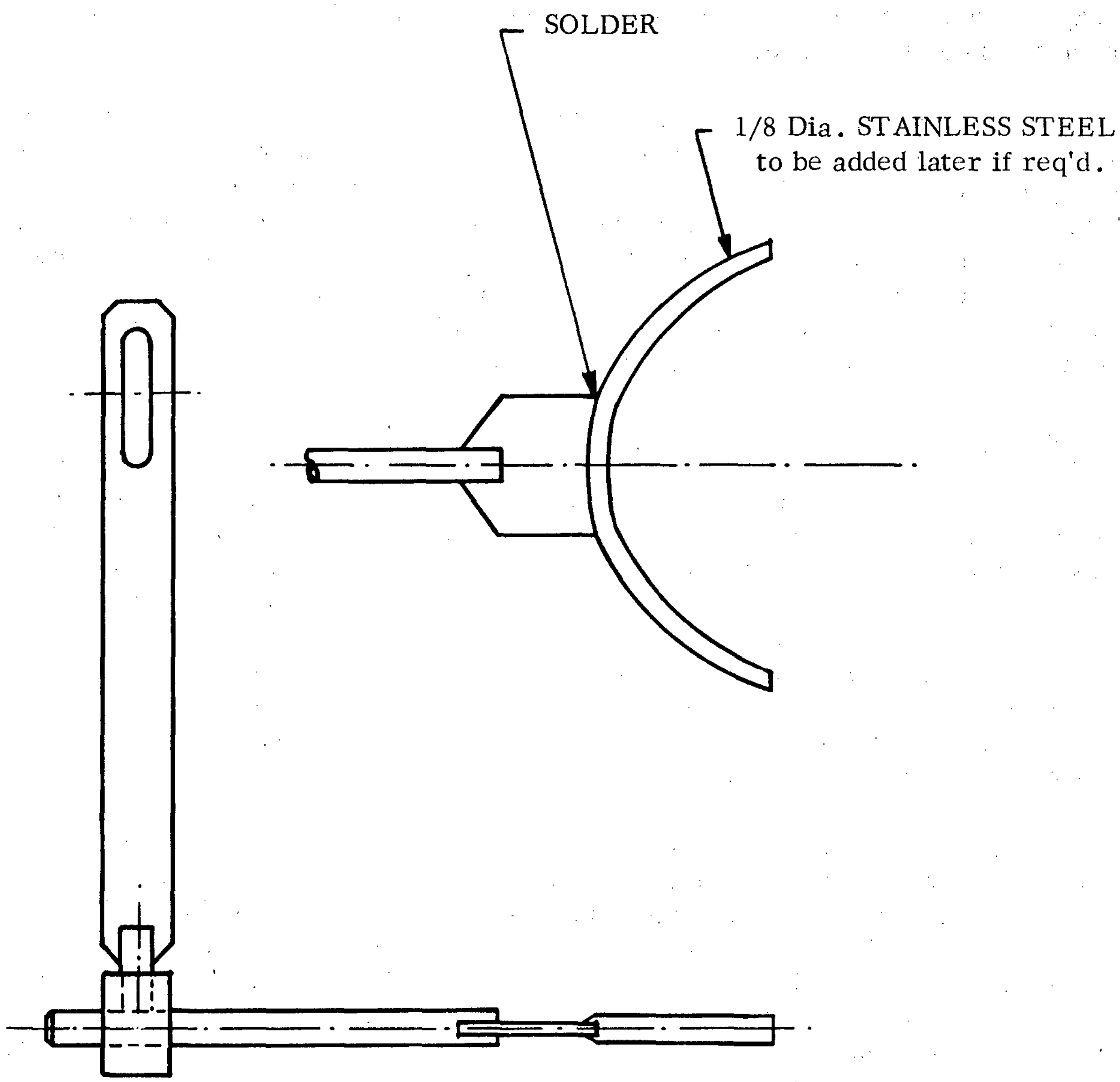

Fig. 8C. BITE BAR ASSEMBLY, ELEVATION VIEW WITH DETAIL VIEW OF OPTIONAL REINFORCED BITE BAR BLADE (Assembly is attached to nose-rest mounting bracket.)

an experienced operator 15-20 minutes; subsequent calibrations on the same subject took approximately 5 minutes.

Early in the study it was determined that the nose steady-rest was not usable for an experiment of this type. The Design Engineering Branch of the Human Engineering Laboratories developed a lightweight bite bar attachment (Figs. 5C-8C) which used the nose steady-rest mounting points and offered no visual interference. LTC K. L. Miller, Chief of Prosthetics, U. S. Army Dental Detachment at Aberdeen Proving Ground, Maryland, provided fitted acrylic bite bars for this attachment. These bite bars were fitted to the subject's upper and lower front teeth from canine to canine and were bonded to the metal portion of the bite bars.

It was felt that the successful use by the study of the EMC-2 system in actual helicopter flight depended on these bite bars. They allowed for quick and accurate calibration; once calibrated it was possible for the subject to make gross and rapid head movements without changing calibration; it was also possible for the subject to open his mouth without disturbing the calibration, and, of special importance, subject discomfort was minimized. There were no complaints from the subjects during or after any of the six flights; the subjects kept the helmets on and bite bars in place in all cases until the aircraft had landed and was shut down even though they had been instructed that they could remove the bite bar as soon as the safety pilot took control of the aircraft. The subjects averaged slightly more than one-half hour of system wearing time for each 20 minute flight.

Problems encountered and documented by other users of this system were known to the author prior to its use, but it was felt that the EMC-2 system was the most appropriate one available for this study because it offered simplicity of data reduction. The HEL-designed bite bars allowed us to secure data where others had encountered unsurmountable difficulties. A minor modification of the film transport system eliminated the film breakage experienced by others. An improved technique for cutting the leading edge of the film was developed to shorten the loading time from more than 30 minutes to two minutes.

One problem the study did not overcome concerned the aperture settings necessary to secure readable film. If the aperture (f) setting was proper for the ambient light and shutter speed used, the exposed film would not show the dot indicating eye fixation point. To correct for this an aperture of four f settings greater was used; for example, the light and shutter speed called for a setting of f 2.2, with aperture settings of f 2.2, f 3.5, f 5.6, f 8 available, a setting of f 8 was necessary to have both the scene and eye fixation dot visible and usable on the film. The study used Plus X Reversal film which has a rather thick and opaque emulsion through which the eye fixation light must penetrate. There are films available which have an essentially transparent emulsion and should alleviate this problem.

Fig. 9C. PILOT S WEARING EMC-2

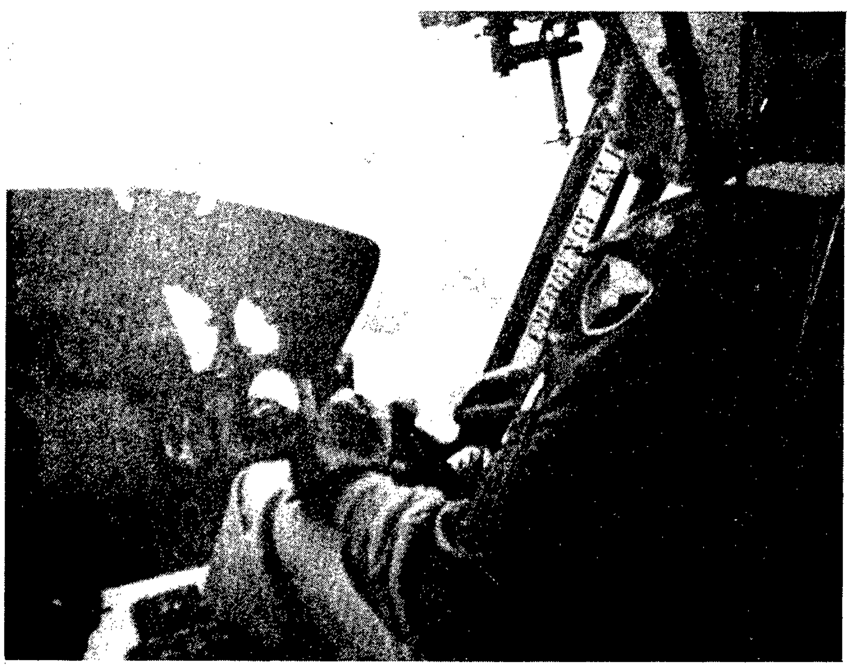

Fig. 10C. PILOT H WEARING EMC-2

Another problem considered was the adverse effect of the aircraft's vibration on photography. Previous experimentation by the Human Engineering Laboratories in the OH-6 helicopter used a motion picture photography of the instrument panel during flight for recording instrument readings. The vibration in this case caused little or no difficulty in reading the instruments, but to be prepared for the worst possible conditions a small bracket was designed to damp the vibrations of the eye-movement camera. This bracket, constructed from 20 gauge steel, was 1/4 inch wide by 2 inches long and was secured to the camera frame by the nose steady-rest mounting bolts. It had a rubber pad bonded to the other end which was in contact with the helmet; this friction provided vibration damping. In actual flight it was not necessary to use this device as the vibration damping action of the pilot's neck was sufficient to take care of any motion encountered in the UH-1.

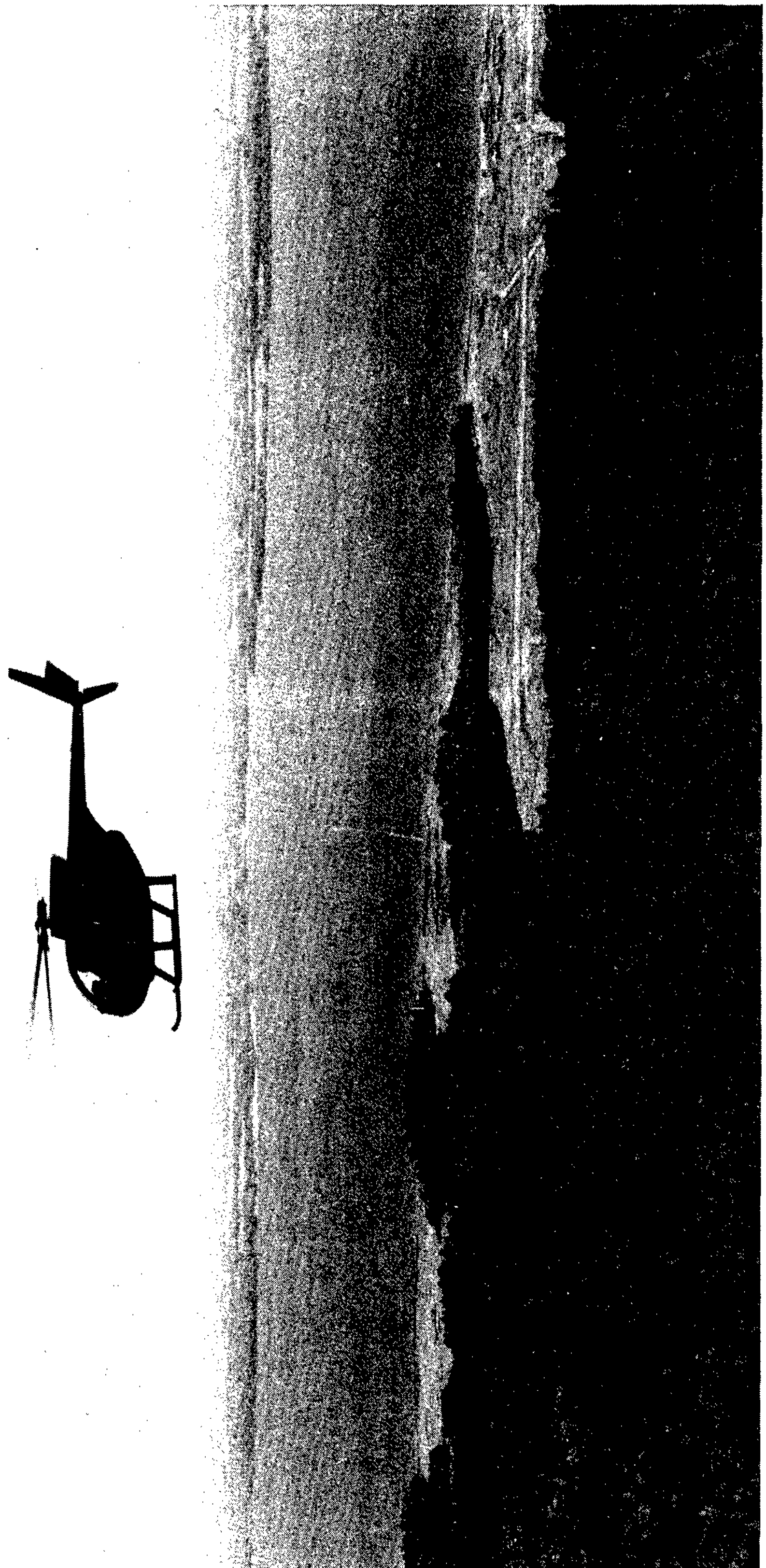

Fig. 11C. OH-6

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13. ABSTRACT

The task requirements of the Tactical Utility Helicopter Mission have been enumerated and experienced pilots have indicated the instrumentation they feel is necessary to perform these tasks.

Film of eye movement was taken for two of the pilots while they were flying missions that encorporated these tasks. The film and the pilot replies were analyzed to provide the information transfer requirements for the Tactical Utility Helicopter flight instrumentation.

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