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VISUAL PERFORMANCE/WORKLOAD OF HELICOPTER PILOTS DURING INSTRUMENT FLIGHT

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SUMMARY

Flight under instrument flight rules (IFR) is reported to be one of the most important factors contributing to aviator fatigue during helicopter operations. This study was initiated to collect visual and psychomotor performance data in an attempt to investigate and study the general visual performance of aviators during IFR conditions. Two groups of aviators, with varied experience levels, were the subjects.

A NAC Eye Mark Recorder and the Helicopter In-Flight Monitoring System were utilized to collect the required data. The results indicated, among other findings, that pilot subjective opinion does not agree with objective data. Additionally, the attitude indicator and radio compass comprised over 60% of the pilots' total visual workload, while the aircraft's status gauges were monitored less than 10% of the total time. These data should provide invaluable information concerning the visual requirements of pilots for safe helicopter operations.

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Commanding

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

The airmobility concept can be defined as the utilization of aerial vehicles organic to the Army to assure the balance of mobility, firepower, intelligence, support, and command and control. The aerial vehicle which has proven to best provide the support for this concept has been the helicopter. Army aircrews, utilizing the helicopter to support the ground fighting forces with rapid transportation, supplies, and medical evacuation, fly under any and all weather conditions. To accomplish these missions, Army aviators are required to fly through meteorological conditions during which they are unable to identify any outside references to aid in the control of their aircraft. This necessitates that they receive all visual cues from cockpit instruments which artificially represent their aircraft's relative spatial and geographical position. This type of flight, which is performed utilizing instruments to fly the aircraft, is referred to as flight under instrument flight rules (IFR).

This IFR flight condition has been referred to in AGARD Advisory Report No. 69[1] as being the most important contributing factor to aviator fatigue during helicopter operations with a possible exception of nap-of-the-earth flight. Additionally, in light of the reported accidents during IFR flights or reduced visibility conditions,[2] it can be concluded that either relevant perceptual cues which exist outside the cockpit are not adequately represented within the cockpit or the information is present but cannot be used effectively. It must be pointed out that optimal rotary wing flight during IFR and reduced visibility conditions is not likely to be achieved by merely representing the outside world in the cockpit via an instrument display. The basic questions of what cues are required for safe flight and how to correctly display them must still be answered.

Several studies have been devised to collect data related to visual performance. These investigations can be divided into three categories: (1) subjective opinions of visual performance, (2) objective visual performance data during fixed wing flight, and (3) objective data during helicopter flight. Studies by Siegel and MacPherson,[3] Clark and Intano,[4] Simmons, et al,[5] have analyzed the opinions of aviators as to which instruments they felt were utilized to fly selected maneuvers. However, these findings do not agree with research results of Frezell, et al;[6] Sanders;[7] and Simmons, et al.[5] These investigators have reported a very poor agreement between subjective data and actual pilot visual performance. Additional studies by Milton, Jones, and Fitts;[8] Fitts, et al;[9] and Diamond[10] have utilized test equipment to obtain objective visual performance data of aviators during flight maneuvers in several fixed wing aircraft. Although these investigations provided useful information as to visual performance during fixed wing flight, data obtained during this work cannot be easily generalized to rotary wing flight because of the extreme aerodynamic differences between airplanes and helicopters.

Sunkes, et al;[11] Stern and Bynum;[12] Frezell, et al,[6] have recorded visual performance in helicopters during selected visual flight rules (VFR) flights. Additionally, two reports[13,14] investigated a number of maneuvers utilizing both the interview technique as well as in-flight recordings of visual performance of two aviators during IFR. These efforts have provided some needed information as to the frequency, duration, and sequence of fixations during helicopter operations. Although all of these studies have provided useful information for the visual performance data base, much investigation remains to be accomplished before a reliable visual performance/workload model can be established for safe helicopter flight.

The purpose of this investigation was to measure the visual performance of helicopter pilots during IFR conditions in an attempt to provide a data base which would not only answer some of the basic questions about visual workload during instrument flight, but would also provide a means of comparing simulated IFR, VFR, night, and nap-of-the-earth flights in helicopters with respect to their varying visual performances and workloads. This information will be invaluable when applied to the development of more efficient training techniques, procedures, and aircraft instrumentation in that a significant reduction in the overall visual performance/workload of the aviator during helicopter operations will be realized.

METHOD

Subjects: Subjects for this investigation were selected from a group of volunteer pilots stationed at Fort Rucker, Alabama. For design purposes subjects were assigned to two general groups of aviators. The first group consisted of five rated helicopter aviators who had no visual problems which would be incompatible with the NAC Eye Mark system, possessed an Army standard instrument rating, were currently on flight status, and had logged less than 250 hours of flight time. For comparisons to past reports this group was designated as student qualified aviators (SQA).

The second group of five subjects possessed the same qualifications as the first with the exception that they had logged over 2400 hours of flight time and were instrument instructor pilots. Again, for comparative reasons, this group was referred to as instrument qualified aviators (IQA). Biographical information for the two groups is presented in Table 1.

TABLE 1

BIOGRAPHICAL SKETCH OF SUBJECTS

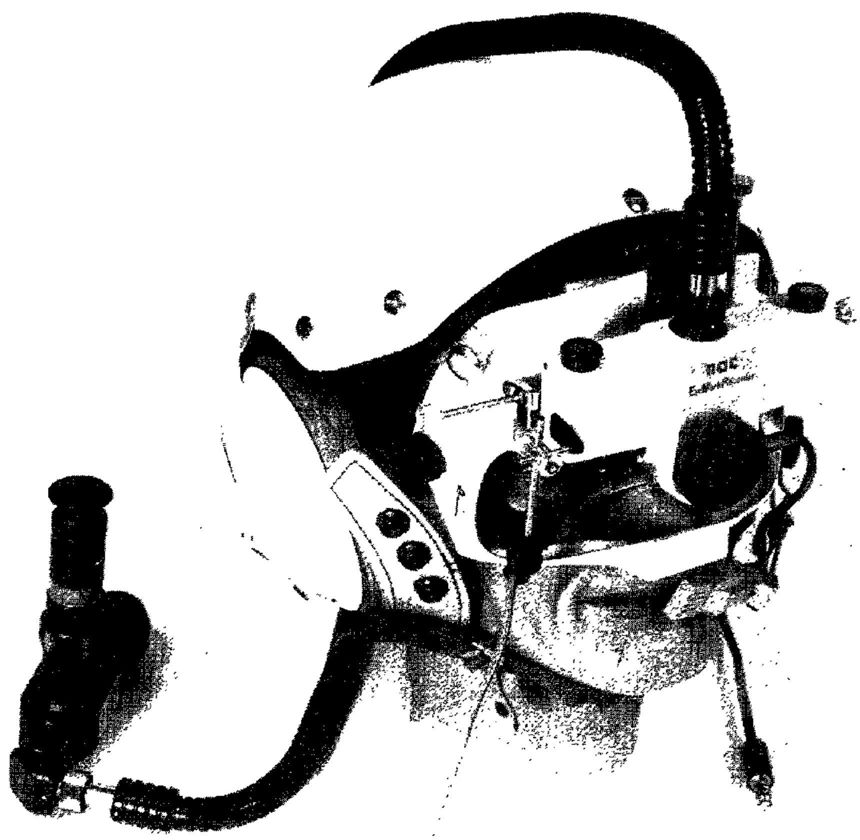
	SQA[1]	IQA[2]
Age Range/Mean	21-29/24.6	27-33/29.60
Years Service Range/Mean	1-4.5/2.6	6-11/7.80
Total Flight Time/Mean	208.28	2452.0
Total Instrument & Hood/Mean	30-50/41.16	100-200/141
Total Instrument & Hood Last 6 Months/Mean	20-45.8/36.16	12-50/36.6

[1] Student Qualified Aviators

[2] Instrument Qualified Aviators

Equipment: Equipment utilized to record visual performance included a NAC Eye Mark Recorder, a LOCAM high speed motion picture camera, and Kodak 4X negative black and white film (ASA 500/400 ft. X 16mm). Flight and psychomotor data were obtained through the use of the Helicopter In-Flight Monitoring System (HIMS).

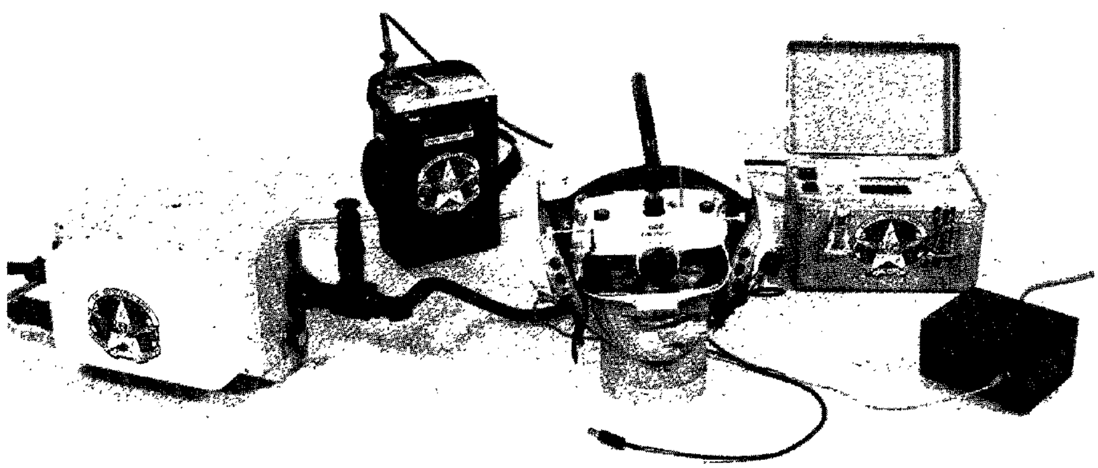
NAC Eye Mark Recorder: The basic device employed to study visual performance/workload was the NAC Eye Mark Recorder which utilizes the corneal reflection technique. Through the application of this technique, fovial fixation points as well as other oculomotor behavior can be detected and recorded. An illuminated reticle is focused on the cornea and reflected by the mirrors on the NAC such that the reticle is superimposed on the pilot's actual field of view. The pilot's eye movement and fixation points are then recorded on 16mm film. A static illustration of the NAC is provided in Figure 1.



NAC EYE MARK RECORDER
FIGURE 1

The complete description, specifications, and operating procedures for the NAC system are outlined in USAARL Report No. 77-4.[15]

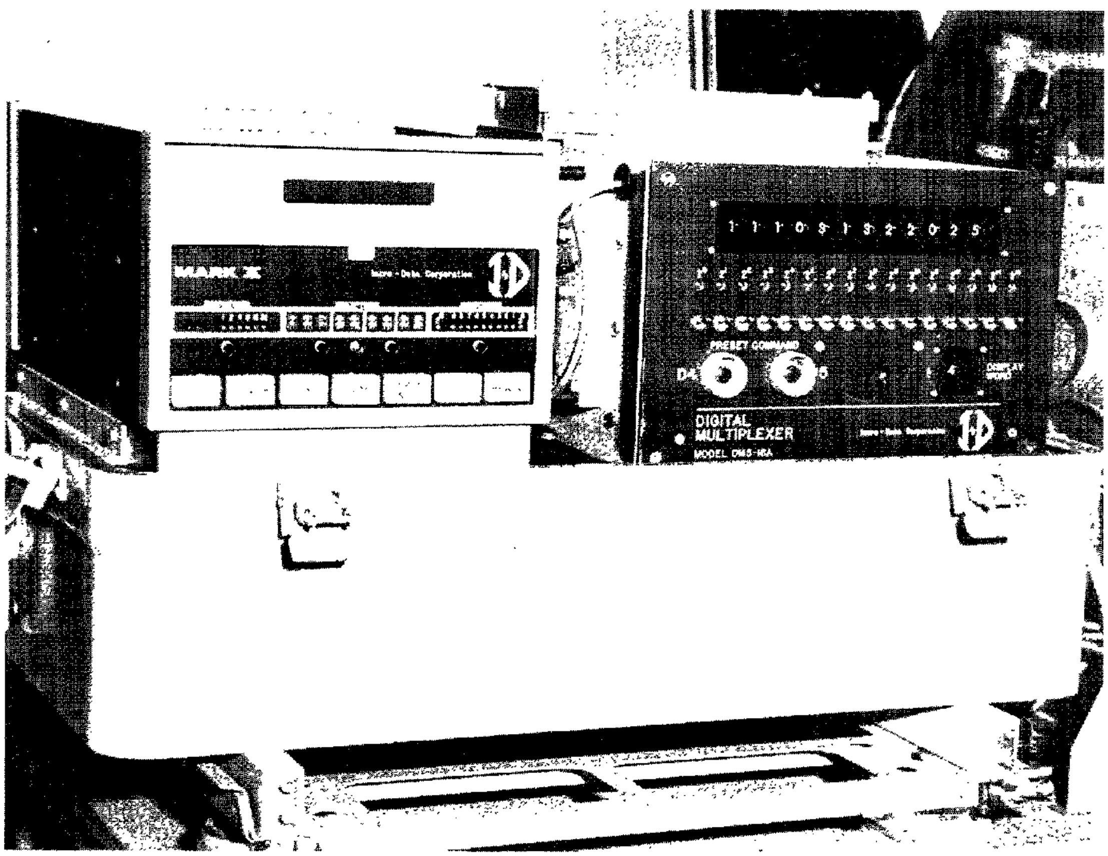
<u>Camera System</u>: The camera arrangement consisted of a LOCAM Model 51-0002 high speed motion picture camera with decoder and time code generator. The NAC/camera arrangement is illustrated in Figure 2.



TOTAL NAC/RECORDING SYSTEM
FIGURE 2

The LOCAM camera with decoder is located to the far left of the picture. The recording adapter and optic bundle link the NAC mask to the camera. Directly behind the camera is a 30 Vdc battery which provides power for the time code generator located to the right of the NAC. The smallest box is a variable power supply which was designed and fabricated by the laboratory to provide a constant power supply for the reticle light of the NAC.

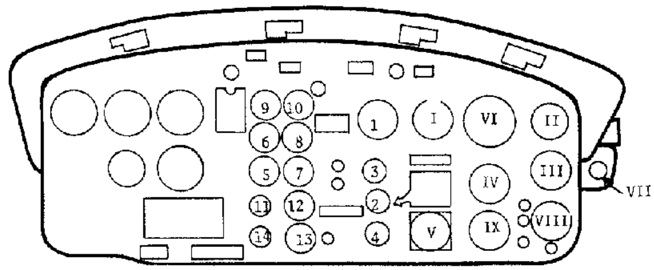
Helicopter In-Flight Monitoring System (HIMS): The HIMS (Figure 3) provided real time acquisition of all major motion and control parameters. The HIMS monitored and recorded aircraft movements in six



HELICOPTER IN-FLIGHT MONITORING SYSTEM (HIMS)
FIGURE 3

degrees of freedom as well as all pilot control movements on the cyclic, collective, pedals, and throttle. Measures of rates and accelerations along each axis were also obtained. A more complete description of this system is available in USAARL No. 72-11.[16]

<u>Aircraft (JUH-1H)</u>: Subjects for this investigation flew in an Army JUH-1H helicopter modified to provide inputs to the HIMS. The aircraft was dual instrumented with the pilot's panel arrangement being standard with the exception of an AAU-32/A Altitude Encoder/Pneumatic altimeter. Figure 4 provides a schematic representation of the UH-1 instrument panel.



MONITORING GAUGES

ENGINE PERFORMANCE

1. ~~Engine RPM~~
2. ~~Gas Producer~~
3. ~~Torque~~
4. ~~Exhaust Temperature~~

OIL STATUS

5. Trans. Oil Pressure
6. Engine Oil Pressure
7. Trans. Oil Temperature
8. Engine Oil Temperature

FUEL STATUS

9. Fuel Pressure
10. Fuel Quantity

ELECTRICAL SYSTEM STATUS

11. Main Generator
12. DC Voltmeter
13. AC Voltmeter
14. Standby Generator

FLIGHT DISPLAYS

I. ~~Airspeed Indicator~~
II. ~~Altimeter~~
III. ~~VSI~~
IV. ~~RMI~~
V. ~~Turn & Bank~~
VI. ~~Artificial Horizon~~
VII. ~~Magnetic Compass~~
VIII. ~~Clock~~
IX. ~~VOR~~

UH-1H INSTRUMENT LAYOUT
FIGURE 4

PROCEDURES

Initial Briefing: The selected subject pilots initially visited the laboratory and were interviewed. During these sessions, subjects were fitted with the NAC mask, briefed about their general responsibilities during the study, and scheduled for the research flight to be initiated from Cairns Army Airfield, Fort Rucker, Alabama.

In-Flight Investigation: On the designated date each subject met the research team at the USAARL Aviation Section at Cairns AAF. During this time the subject pilot was briefed. He was to be the pilot in command during an instrument flight which would be initiated from Runway 36, where the pilot was to perform an instrument takeoff, track in-bound to the Enterprise nondirectional beacon, perform some basic IFR flight maneuvers at the command of the safety pilot, and finally perform an ILS approach to Runway 06 at Cairns. After this briefing the subject was fitted with the NAC and the system was calibrated. The subject then proceeded to the aircraft where he was seated and the normal safety procedures of fastening restraints and checking communications were accomplished. The NAC system was connected to the camera system and fine adjustment of the NAC performed.

Before starting the test profile, the helicopter was hovered from three to five minutes to allow the NAC time to settle on the subject's head. This time was utilized to move the aircraft from its parking location to the taxiway short of the designated runway. The NAC was adjusted for the final time and the camera turned on.

The profile, as described, consisted of requiring the subject pilot to fly under instrument conditions toward the Enterprise nondirectional beacon. During this enroute phase, the subject was to perform, on command, a variety of basic instrument flight maneuvers to include level flight, climbs, turns, climbing turns, descending turns, and straight descents. For purposes of this investigation, these maneuvers are defined in Table 2. Figure 5 demonstrates the mission profile. Average time for these research flights was 30 minutes. Because of the limitation of film capacity, cameras were changed about midway through the profile and calibration of the NAC was checked. This calibration check was again performed after the completion of the profile.

TABLE 2

FLIGHT MANEUVERS IN THE UH-1 (IFR)

<u>Instrument Takeoff (ITO)</u> - Is defined from complete stop on the active runway through lift off to 450 ft., maintaining runway heading.

<u>Climb</u> - Is defined as straight ascent of at least 1000 ft. maintaining a constant heading with standard school procedures ($\pm$ 10 knots airspeed and 500 FPM) No separate navigation task was assigned.

<u>Cruise</u> - Is defined in this study as level flight for at least one minute, maintaining standard school procedures with no additional task assigned other than maintaining constant heading.

<u>Descent</u>- Is defined as the intentional loss of altitude of at least 1000 ft., maintaining a constant heading following school procedures with no additional task assigned.

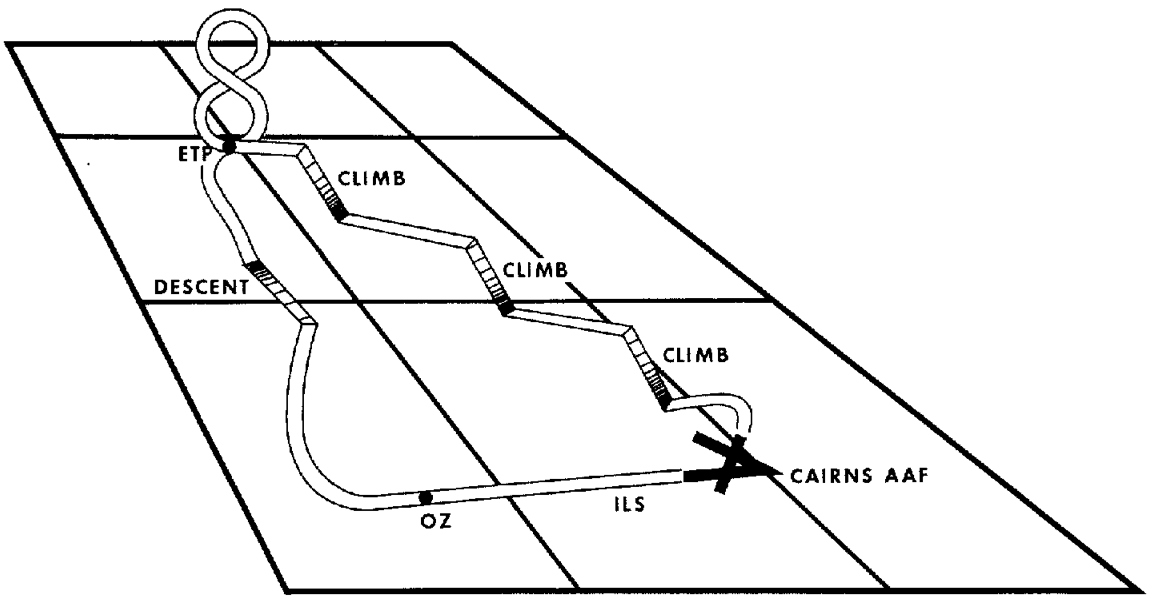
<u>Climbing Turn</u> - Was performed by simultaneously changing direction of 180 degrees and climbing 500 ft. No other task assigned.

<u>Descending Turn</u> - Was the simultaneous descending and turning 500 ft. at 180 degrees. No other task assigned.

<u>Level Turn</u> - Was performed by banking the aircraft and turning while maintaining constant altitude and airspeed. No other task assigned.

<u>Instrument Landing (ILS)</u> - Is defined in this study as the published ILS approach RWY6 to Cairns Army Airfield. The maneuver began at Cairns outer marker (OM) and ended at Cairns middle marker (MM). This maneuver differed from all other maneuvers in that the additional task of monitoring the OBS gauge was required.

After mission termination the subject was debriefed and given a short questionnaire which requested his impressions of his visual performance during the various maneuvers. An example of the questionnaire is provided in Appendix A.



MISSION PROFILE
FIGURE 5

Measurements: Continuous information was recorded pertaining to the ten subject pilots' visual and psychomotor performance as well as the status and control response of the aircraft. Oculomotor behavior was collected at 16 data points per second. Twelve areas were selected which best described the pilots' visual performance. A thirteenth area was labeled "all other areas." If the percentage of time spent monitoring this area was significantly low it could be assumed that the other twelve areas accurately represented the total visual performance of the subjects. A list of these areas is presented in Table 3.

TABLE 3

THIRTEEN VISUAL DATA POINTS

1.	REST	All other areas not included in the following twelve areas:
2.	ALT	AAU-32/A Altitude Encoder/Pneumatic Altimeter
3.	VSI	Standard UH-1 Vertical Velocity Indicator
4.	OBS	Standard UH-1 Omni Indicator
5.	T&B	Standard UH-1 Turn and Slip Indicator
6.	RMI	Standard UH-1 Radio Magnetic Compass
7.	AH	Standard UH-1 Pilot's Attitude Indicator
8.	AS	Standard UH-1 Airspeed Indicator
9.	TORQ	Series of instruments including the Torquemeter, Gas Producer Tachometer, and Exhaust Gas Temperature Indicator.
10.	RPM	Dual Rotor and Engine Tachometer
11.	ELEC	The electrical gauges which include AC and DC Voltmeters and the main and standby Generator Loadmeters.
12.	OIL	The oil monitoring gauges to include Engine and Transmission Oil Temperature and Pressure gauges.
13.	FUEL	The Fuel Pressure and Fuel Quantity gauges

Twenty data points per second were recorded from eighteen pilot and aircraft parameters via HIMS. These pilot and aircraft parameters were mainly utilized to judge the quality of each flight. Those utilized for this work are listed in Table 4.

TABLE 4

PERFORMANCE MEASURES DERIVED FROM HIMS

	PARAMETER	MEASURE
1.	Fore/Aft Cyclic	-Standard Deviation
		-Movement Per Second
		-Percent of Steady State
2.	Left/Right Cyclic	-Standard Deviation
		-Movement Per Second
		-Percent of Steady State
3.	Collective	-Standard Deviation
		-Movement Per Second
		-Percent of Steady State
4.	Pedals	-Standard Deviation
		-Movement Per Second
		-Percent of Steady State
5.	Pitch	-Standard Deviation
6.	Turn Rate	-Standard Deviation
7.	Climb Rate	-Standard Deviation
8.	Heading	-Standard Deviation
9.	Altitude	-Standard Deviation
10.	Airspeed	-Standard Deviation

ANALYSIS AND RESULTS

Visual Performance: Visual Performance was analyzed for each of the eight maneuvers described in Table 2. Reduction of the film data provided seconds per maneuver that fixations were recorded within each of the thirteen areas described in Table 3. In addition, the number of fixations per area and the first generation link values for each of these areas were recorded. From these values, the percentage of time spent within each area per maneuver was computed as well as mean dwell time and scan rate per minute for each area. The definitions and formulas utilized for these measures are found in Table 5.

TABLE 5

DESCRIPTION OF BASIC AND DERIVED VISUAL MEASURES

UNIT	DEFINITION	SYMBOL/FORMULA
1. Fixation	The stationary eye movement within a designated area for at least 100 milliseconds	F
2. Number	The sum of fixations on a designated area (instrument)	N
3. Time	The sum of time spent fixated on a designated area (instrument)	T
4. Link Values	The visual path traveled from one area (instrument) to another	LV
5. Dwell Time	Mean time fixated per area	$DT = T/N$
6. Percent of Time	The percentage of lapse time during a maneuver which was allotted to each area	$\%T = T/\Sigma T \times 100$
7. Percent of Number	The percentage of fixations during a maneuver allotted to each area	$TN = N/\Sigma N \times 100$
8. Scan Rate	The rate that each area was fixated	$SR = N/\Sigma T \times 60$

These visual data for each subject were combined into appropriate groups and the results are reflected by Tables 6 through 17 located in Appendix B. Tables 6 and 7 denote the percentages of lapse time along with the standard deviation for each group for each of the flight segments during which the thirteen areas were fixated. The data shown in Tables 8 and 9 are the percentages of fixations per instrument for each of the flight segments. The data depicted in Tables 10 and 11 represent the mean dwell time spent viewing each instrument. The presentation of the data in percentages and rates allows the results to be compared across maneuvers and subject groups regardless of subject variance in time required to complete the maneuvers.

The link values between the thirteen areas for each group of subjects are presented in Tables 12 through 17. The top values are link values of the low time aviators (SQA) while the lower values are for the instructor pilots (IQA).

Figures 6 through 13 (Appendix C) graphically illustrate the percentage of lapsed time each group spent within each area. The solid bar represents values for the IQA group and the broken bar those of the SQA group. Scan rate and lapsed time differences were minimal across groups; therefore, scan rate data are not presented.

From inspection of the mean values, it was determined that the RPM, electrical, oil, and fuel gauges comprised less than one percent of the scan rate or percentage of lapse time measures obtained during most of the maneuvers. Because these values were extremely low, and at times zero, they were eliminated from the statistical analyses. Additionally, the visual area labeled "all other areas" typically comprised only one percent of the total lapsed time and was deleted. Finally, the gauges described in the "torque" area were noted; but because this area represented three gauges which confounded the results and because it was not homogeneous with the remaining flight gauges, it too was excluded from the remaining tests. The statistical analysis was performed utilizing the remaining seven areas. These areas were the altimeter, vertical speed indicator, radio magnetic compass, attitude indicator, airspeed indicator, turn and bank indicator, and omni indicator. These instruments could best be described as aircraft flight displays, and those gauges which were excluded, as aircraft monitoring gauges. The final analyses were performed between two groups of subjects across the eight flight maneuvers. The visual performance measures of the seven flight instruments were utilized as dependent variables for these analyses.

Multivariate and univariate analyses were performed employing group scan rates, dwell times, and percentage of lapse times, to determine if one of these measures was superior in describing visual performance differences between subject groups or maneuvers. Initially, a multivariate analysis of variance test (MANOVA) of the percentage time was performed between the two groups of subjects, eight maneuvers, and seven flight gauges. The results are shown in Table 18.

TABLE 18

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR ALL MANEUVERS

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	8.427	7.0	2.0	.110	.983
MANEUVERS	7.386	49	258.26	.001	.967
	2.951	36	240.973	.001	.771
	1.849	25	217.761	.011	.613
GROUP-MANEUVER INTERACTION	1.255	49	258.26	.135	.614

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

The group and group-maneuver interactions were not significant; however, as was expected, there were differences across maneuvers. Next, from viewing the graphs in Figures 7, 8, and 9, the climb, cruise, and descent portion of the flight profile appeared to contain similar visual fixations data. Visual performance during these three maneuvers was tested by MANOVA and no significant differences were found between groups, the group-maneuver interaction, or across maneuvers (Table 19).

TABLE 19

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	2.683	7.0	2.0	.224	.918
MANEUVERS	.639	14.0	20.0	.804	.700
GROUP-MANEUVER INTERACTION	1.882	14.0	20.0	.096	.848

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

Because these three maneuvers demonstrated no significant differences they were tested, in turn, against the remaining maneuvers. The results of these three maneuvers compared to the ITO are shown in Table 20, the ILS in Table 21, climbing turns in Table 22, descending turns in Table 23, and level turns in Table 24.

The MANOVA was utilized next to test the difference between group dwell times during each maneuver. Again, comparisons between visual dwell time during climb, cruise, and descent demonstrated no significant differences. These three maneuvers were compared in turn with each of the remaining maneuvers. Significant differences were found when data from these maneuvers were compared against the ILS (Table 25). When the scan rate data were submitted to an identical test, significant differences were observed between the three maneuvers, the ITO (Table 26) and the ILS (Table 27).

TABLE 20

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT, ITO

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	8.568	7.0	2.0	.108	.984
MANEUVERS	2.624	21.0	52.236	.002	.903
GROUP-MANEUVER INTERACTION	.941	21.0	52.236	.545	.723

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 21

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT, ILS

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	17.221	7.0	2.0	.056	.992
MANEUVERS	6.445	21.0	52.236	.001	.979
GROUP-MANEUVER INTERACTION	1.972	2.10	52.236	.024	.759

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 22

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT, CLIMBING TURN

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	524.491	7.0	2.0	.034	1.0
MANEUVERS	1.826	21.0	52.236	.040	.830
GROUP-MANEUVER INTERACTION	1.273	21.0	52.236	.237	.718

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 23

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT, DESCENDING TURN

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	8.059	7.0	2.0	.115	.983
MANEUVERS	1.928	21.0	52.236	.028	.850
GROUP-MANEUVER INTERACTION	1.661	21.0	52.236	.070	.755

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 24

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
PERCENT OF LAPSE TIME FOR CLIMB, CRUISE, DESCENT, LEVEL TURN

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	5.495	7.0	2.0	.163	.975
MANEUVERS	2.346	21.0	52.236	.007	.860
GROUP-MANEUVER INTERACTION	1.282	21.0	52.236	.230	.773

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 25

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
DWELL TIME FOR CLIMB, CRUISE, DESCENT, ILS

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	.322	7.0	2.0	.892	.728
MANEUVERS	2.263	21.0	52.236	.009	.894
GROUP-MANEUVER INTERACTION	.963	21.0	52.236	.520	.740

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 26

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
SCAN RATE FOR CLIMB, CRUISE, DESCENT, ITO

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	3.813	7.0	2.0	.223	.965
MANEUVERS	2.864	21.0	52.236	.001	.913
GROUP-MANEUVER INTERACTION	.714	21.0	52.236	.800	.671

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

TABLE 27

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY:
SCAN RATE FOR CLIMB, CRUISE, DESCENT, ILS

SOURCE	F-RATIO	HYPOTHESIS df	ERROR df	P LESS THAN	CANONICAL R
GROUPS	4.287	7.0	2.0	.202	.968
MANEUVERS	7.115	21.0	52.236	.001	.980
GROUP-MANEUVER INTERACTION	1.168	21.0	52.236	.316	.716

Significant test uses Wilks-Lambda criterion. The third factor was subjects and was used in creating appropriate error terms for the primary comparisons.

It may be noted in the above multivariate comparisons that the degrees of freedom for the test were relatively few in number, resulting in an extremely conservative test of the experience level and maneuver main effects. However, since the main purpose of these comparisons was to determine if there were any major differences between visual performance on these factors, this conservatism is considered appropriate.

Because of the results of the MANOVA, univariate F tests associated with significant visual performance variables were examined as an aid in describing changes in visual performance across maneuvers. The groups differed in performance during climb, cruise, and descent only in the percent of time fixated on the turn and bank indicator ($F = 11.087$, $DF = 1/8$, $P < .01$). This same group difference was found testing each of the remaining maneuvers as illustrated in the test of the three maneuvers against the ITO ($F = 21.222$, $DF = 1/8$, $P < .002$). There were no other group differences noted during the univariate tests of the percentage of time, scan rate, or the dwell times.

The significant results of the univariate F test of the maneuvers utilizing percentage of lapsed-time measure are presented in Table 28 and the results of the same test of the maneuvers with the scan rate measure are shown in Table 29.

TABLE 28

UNIVARIATE F TEST OF MANEUVERS/PERCENT OF TIME

		ALT	VSI	T&B	RMI	AH	AS	OBS
CLIMB, CRUISE, DESCENT	F							
	P							
CLIMB, CRUISE, DESCENT AND ITO	F	9.61	13.44			8.53		
	P	.001	.001			.001		
CLIMB, CRUISE, DESCENT AND ILS	F	14.05	3.84	5.41	7.80	7.66		146.75
	P	.001	.02	.005	.001	.001		.001
CLIMB, CRUISE, DESCENT AND DESCENDING TURNS	F			4.02	11.73	3.14		
	P			.02	.001	.04		
CLIMB, CRUISE, DESCENT AND CLIMBING TURNS	F		3.60	7.38				
	P		.03	.001				
CLIMB, CRUISE, DESCENT AND LEVEL TURNS	F	3.43	6.57					
	P	.03	.002					

TABLE 29

UNIVARIATE F TEST OF MANEUVERS/SCAN RATE

		ALT	VSI	T&B	RMI	AH	AS	OBS
CLIMB, CRUISE, DESCENT	F	4.98						
	P	.02						
CLIMB, CRUISE, DESCENT AND ITO	F	6.45	8.75		5.40			
	P	.002	.001		.006			
CLIMB, CRUISE, DESCENT AND ILS	F	11.94		3.14	9.26	16.67		128.73
	P	.001		.04	.001	.001		.001
CLIMB, CRUISE, DESCENT AND DESCENDING TURNS	F			4.71	6.64			
	P			.01	.002			
CLIMB, CRUISE, DESCENT AND CLIMBING TURNS	F			4.78				
	P			.009				
CLIMB, CRUISE, DESCENT AND LEVEL TURNS	F		3.28					
	P		.04					

A stepwise discriminant analysis was performed utilizing the scores of the seven instrument flight displays which had previously been chosen. Separate analyses were performed for the percent of lapse time, scan rate, and dwell time. A stepwise discriminate analysis was utilized to determine if the variables could effectively define changes in visual performance between groups and maneuvers. The two subject groups were tested to determine if they could be classified by the 39 variables. Table 30 reflects the results of this test. From these results, it can be demonstrated that dwell time was not a good discriminator of groups.

TABLE 30

STEPWISE DISCRIMINANT ANALYSIS
CLASSIFICATION OF SUBJECT GROUPS

VARIABLE USED	GROUP	CLASSIFIED AS:	SQA	IQA	PERCENT
Dwell Time	IQA		11	27	71
	SQA		26	12	68
Scan Rate	IQA		7	31	81
	SQA		32	6	84
% of Time	IQA		7	31	84
	SQA		33	5	86

Finally, the same stepwise discriminant analysis, utilizing the seven variables simultaneously, was performed to determine if the maneuvers could be correctly classified. Tables 31 through 34 reflect the results of these tests.

Psychomotor and Aircraft Performance: Psychomotor and aircraft performance was measured via the HIMS. Because of equipment malfunctions, some of these data were lost. Of the ten subjects, two SQA psychomotor/aircraft data were lost and three from the IQA group. Table 35 is the two group psychomotor parameters and Table 36 the aircraft parameters. The SQA group demonstrated a trend of less control inputs and more time in control steady state (Table 35). They also had a better aircraft performance (Table 36).

TABLE 31

STEPWISE DISCRIMINANT ANALYSIS
CLASSIFICATION OF MANEUVERS UTILIZING PERCENTAGE OF LAPSE TIME

	CLIMB	CRUISE	DESCENT	CLIMBING TURN	DESCENDING TURN	LEVEL TURN	ILS	ITO	% CORRECT
CLIMB	9	9	6	5	0	2	1	4	25
CRUISE	3	11	3	4	3	8	0	1	33
DESCENT	0	3	9	0	0	0	0	2	64
CLIMBING TURN	1	5	4	3	7	2	0	3	12
DESCENDING TURN	0	0	1	4	10	1	0	1	59
LEVEL TURN	3	0	3	2	1	3	2	5	16
ILS	0	0	0	0	0	1	8	0	89
ITO	0	1	0	1	0	0	0	7	78

TABLE 32

STEPWISE DISCRIMINANT ANALYSIS
CLASSIFICATION OF MANEUVERS UTILIZING DWELL TIME

	CLIMB	CRUISE	DESCENT	CLIMBING TURN	DESCENDING TURN	LEVEL TURN	ILS	ITO	% CORRECT
CLIMB	11	5	6	4	2	4	2	2	30
CRUISE	6	4	3	6	0	6	4	4	12
DESCENT	2	0	5	2	1	1	3	0	35
CLIMBING TURN	2	4	2	5	5	1	1	5	20
DESCENDING TURN	1	1	0	5	10	0	1	1	59
LEVEL TURN	1	2	1	3	2	7	3	0	37
ILS	0	0	0	0	0	0	9	0	100
ITO	1	1	0	0	1	0	1	5	56

TABLE 33

STEPWISE DISCRIMINANT ANALYSIS
CLASSIFICATION OF MANEUVERS UTILIZING SCAN RATE

	CLIMB	CRUISE	DESCENT	CLIMBING TURN	DESCENDING TURN	LEVEL TURN	ILS	ITO	% CORRECT
CLIMB	4	10	7	3	3	4	1	4	11
CRUISE	1	13	5	3	4	6	1	0	39
DESCENT	3	0	4	2	1	4	0	0	28
CLIMBING TURN	1	6	3	6	6	0	1	2	24
DESCENDING TURN	2	0	0	3	11	0	0	1	64
LEVEL TURN	1	2	0	2	1	11	1	1	57
ILS	0	0	0	0	0	0	9	0	100
ITO	0	1	1	1	0	0	0	6	67

TABLE 34

STEPWISE DISCRIMINANT ANALYSIS
CLASSIFICATION OF MANEUVERS UTILIZING PERCENTAGE, DWELL TIME, SCAN RATE

	CLIMB	CRUISE	DESCENT	CLIMBING TURN	DESCENDING TURN	LEVEL TURN	ILS	ITO	% CORRECT
CLIMB	11	7	10	4	1	2	1	0	30
CRUISE	9	8	4	5	1	5	0	1	24
DESCENT	1	1	11	1	0	0	0	0	78
CLIMBING TURN	2	4	1	12	4	1	0	1	48
DESCENDING TURN	1	0	0	5	10	0	0	1	58
LEVEL TURN	1	2	1	3	1	10	1	0	52
ILS	0	0	0	0	0	0	9	0	100
ITO	0	0	0	1	0	0	0	8	88

TABLE 35

SUBJECT PSYCHOMOTOR PERFORMANCE PER MANEUVER

		FORE/AFT CYCLIC			LEFT/RIGHT CYCLIC			COLLECTIVE			PEDALS		
		SD	M/S[1]	% S/S[2]	SD	M/S	% S/S	SD	M/S	% S/S	SD	M/S	% S/S
ITO	IQA	.348	.916	57.4	.199	.985	53.1	.187	.231	92.6	.499	.399	86.2
	SQA	.307	.552	76.3	.113	.851	70.3	.107	.247	93.5	.133	.029	98.8
CLIMB	IQA	.118	.781	76.2	.154	1.200	59.9	.091	.228	94.4	.099	.083	98.4
	SQA	.167	.953	67.9	.159	1.04	62.5	.162	.245	92.5	.081	.031	99.3
LEVEL	IQA	.145	.849	75.5	.165	1.260	61.9	.202	.324	92.7	.068	.041	99.2
	SQA	.138	.746	77.8	.158	.868	72.1	.140	.256	93.5	.049	.014	99.8
DESCENT	IQA	.176	.684	79.0	.198	.942	71.4	.296	.223	93.9	.110	.047	99.0
	SQA	.137	.520	86.8	.161	.699	79.8	.216	.199	93.9	.097	.014	99.6
CLIMBING TURN	IQA	.217	.832	74.9	.195	1.043	66.6	.212	.246	94.1	.083	.048	99.2
	SQA	.217	.902	70.2	.237	1.008	64.7	.250	.270	93.5	.081	.016	99.8
DESCENDING TURN	IQA	.226	.616	80.3	.191	.837	76.8	.268	.286	92.5	.106	.045	99.2
	SQA	.245	.662	79.2	.214	.727	79.1	.252	.185	94.4	.084	.015	99.7
LEVEL TURN	IQA	.125	.517	79.2	.174	.943	61.2	.135	.320	92.7	.075	.046	98.6
	SQA	.122	.516	84.3	.157	.577	83.8	.048	.238	92.5	.022	.004	99.9
ILS	IQA	.141	.920	72.9	.218	1.197	56.5	.177	.243	93.5	.127	.163	97.9
	SQA	.237	1.085	65.8	.225	1.252	55.5	.321	.233	93.2	.114	.030	99.5

TABLE 36

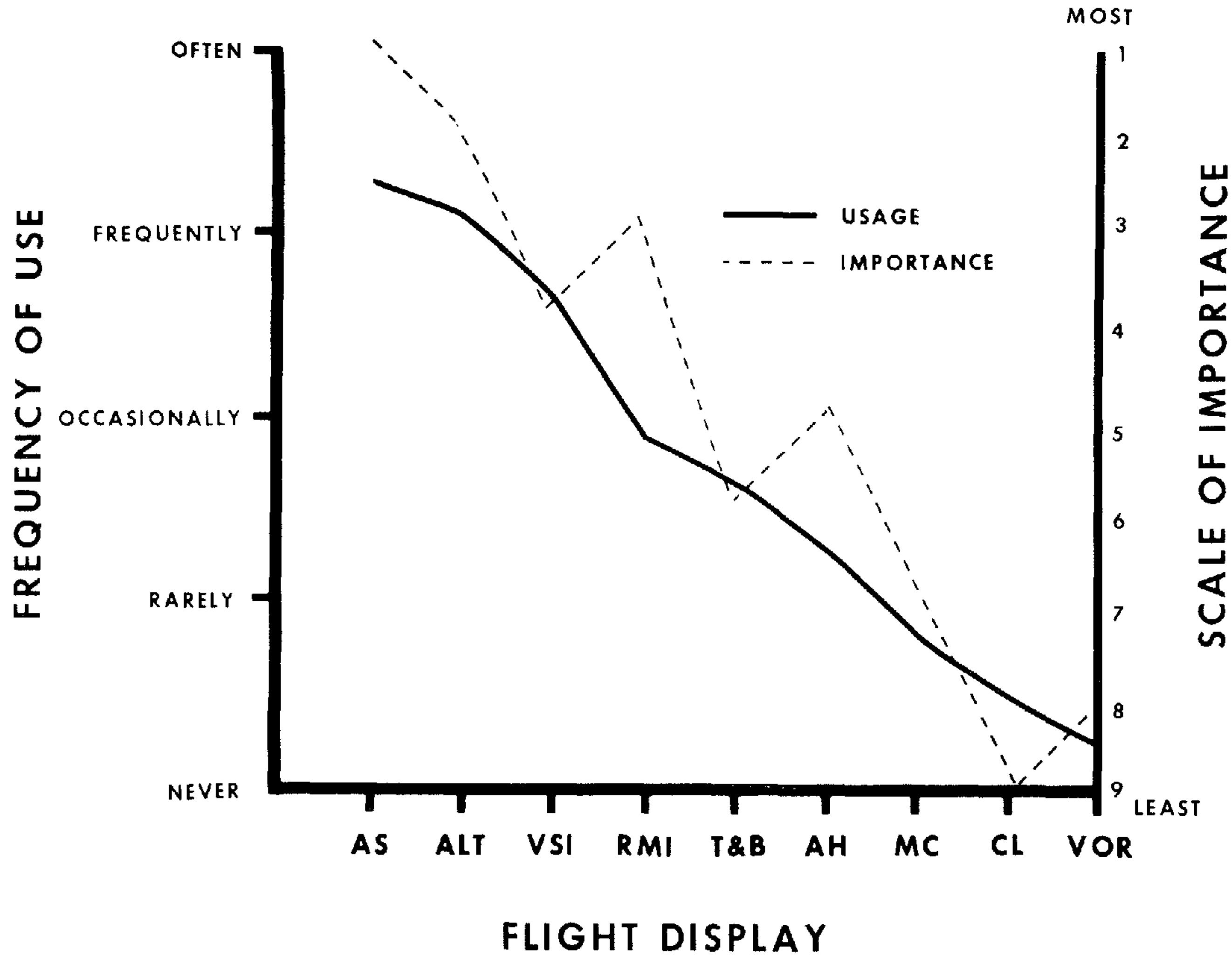
AIRCRAFT PERFORMANCE PER MANEUVER

		PITCH/SD	TURN RATE/SD	CLIMB RATE/SD	HEADING/SD	ALTITUDE/SD	AIRSPEED/SD
ITO	IQA	1.358			2.54		
	SQA	1.006			1.78		
CLIMB	IQA	1.543		129.42	4.36		4.39
	SQA	1.439		102.58	4.12		3.58
LEVEL	IQA	1.239			2.54	31.02	4.03
	SQA	1.314			5.75	24.18	3.57
DESCENT	IQA	1.208		133.66	4.96		3.18
	SQA	1.019		107.57	5.18		3.23
CLIMBING	IQA	1.806	2.37	127.52			4.99
TURN	SQA	1.918	2.57	95.94			4.29
DESCENDING	IQA	1.326	2.46	114.06			4.36
TURN	SQA	1.977	2.42	104.12			4.21
LEVEL	IQA	.977	2.32			39.39	2.27
TURN	SQA	1.213	2.27			22.44	2.87
ILS	IQA	1.328		90.17	3.86		4.21
	SQA	1.839		91.35	4.29		5.28

Questionnaire: Following each test flight, subjects were provided a pilot's opinion questionnaire which had been prepared for USAARL Report No. 76-18, "Pilot Opinion of Flight Displays and Monitoring Gauges in the UH-1 Helicopter."[17] An example of this questionnaire is in Appendix A. The sections of the questionnaire which closely relate to the objective data are the frequency of use and importance which each aviator rated the flight instruments during climb, cruise, and descent. Current aviator responses were compared to responses of the original group of aviators who had answered these same questions. For each section and display category, a Kendall's Coefficient of Concordance (W) was computed to determine the relationship between ranks for the two subject groups. The coefficient of concordance (W) for the two groups for the frequency of use of the flight display during climb, cruise, and descent as well as the order of importance were significant at the .01 level indicating a high level of agreement between the two groups. Current and past aviator opinions are presented in Table 37. Figure 14 reflects the mean responses of how often or how rarely the aviators felt they used the flight instruments.

TABLE 37
PILOT OPINION: FREQUENCY OF USE OF INSTRUMENTS

	FREQUENCY OF USE					
MONITORING GAUGES	**RUN UP**	**HOVERING**	**PRE-TAKEOFF**	**CLIMB**	**CRUISE**	**DESCENT**
ENGINE PERFORMANCE						
ENGINE RPM	1	1	1	1	1	1
GAS PRODUCER	7	2	7	2	2	2
TORQUE	9	3	10	3	3	3
EXHAUST TEMP.	3	4	8	4	4	4
TREND INFORMATION						
TRANS. OIL PRESS.	4	5–7	3–4	5	5	6
ENG. OIL PRESS.	2	5–7	2	7–8	9	5
TRANS. OIL TEMP.	6	5–7	5	6	7–8	7–8
ENG. OIL TEMP.	5	8	3–4	7–8	7–8	7–8
FUEL MANAGEMENT						
FUEL PRESSURE	10	10	9	9	10	10
FUEL QUANTITY	8	9	6	10	6	9
ELECTRICAL SYSTEMS						
MAIN GENERATOR	13	11	11–12	11–12	11	11
DC VOLTMETER	11	12	11–12	13	12	12
AC VOLTMETER	12	13	13	11–12	13	13
STANDBY GEN.	14	14	14	14	14	14
X^2 <	.01	.001	.05	.01	.001	.001
W^r <	.01	.001	.01	.001	.01	.001
FLIGHT GAUGES						
AIRSPEED INDICATOR				1	1	1
ALTIMETER				2	2	2
VSI				3	3	3
RMI				4	4	5
TURN & BANK				5	6	4
ARTIFICIAL HORIZON		NA		6	5	6
MAGNETIC COMPASS				7	7	7
CLOCK				8	8	8
VOR				9	9	9
X^2 <				.01	.01	.01
W^r <				.01	.01	.01



COMPARISON OF PILOT OPINION OF IMPORTANCE VS USAGE OF FLIGHT DISPLAY

FIGURE 14

DISCUSSION

The visual data which have been reported to this point were collected to develop a pilot visual performance data base during helicopter flight. The maneuvers were flown under instrument flight rules, and varied from an ITO through climbs, cruise, descents, and turns, which are basic IFR maneuvers with no navigation tasks, and finally included an ILS. Aviator visual performance during these maneuvers is quite complicated as is indicated by the numerous tables and figures which have been utilized thus far in an attempt to describe the data.

The data base is essential however, because there appears to be no other method to determine what cues are required for safe helicopter flight. The questionnaire data demonstrate, when compared to Figures 5 through 16, that aviators' opinions do not agree with their own objective visual data. Although subjectively aviators feel that the attitude indicator and radio magnetic compass ranked very low in priority of use, visually they depended very heavily on the same two instruments. The visual performance related to these two instruments combined accounted for two-thirds of their total visual lapse time across all maneuvers.

Utilization of the attitude indicator and radio magnetic compass seems to indicate that pilots place a high priority on maintenance of the aircraft's stability about its major axes (pitch, roll, and yaw). The data of the present study would support this assumption in that before a pilot can utilize fine detailed information about his flight, he needs to determine that the aircraft is positioned spatially about these three axes. Only after this is ascertained would the pilot scan other instruments for fine detail.

Projecting this line of thought, the instrument panel can be divided into three separate zones. The first zone which could be labeled "aircraft stability management" would include the attitude indicator for pitch and roll information, and both the radio magnetic compass and turn and bank indicator for yaw information. Data obtained about the turn and bank link values (Tables 12 through 17) support that it be classified with the other two instruments. To gain this stability information from these instruments would require the pilot to perform simple visual tracking tasks in contrast to reading quantitative information from other instruments such as the altimeter or airspeed indicator.

The second zone provides the finely detailed information about current aircraft status such as exact altitude or airspeed. This zone could be labeled "quality flight management" and would include the altimeter, airspeed indicator, and vertical speed indicator. Instruments in this zone would be utilized only when the monitoring of zone one was not critical.

The final zone would be comprised of the remaining instruments which include special navigation instruments and aircraft monitoring gauges. This third zone could be termed "special requirement gauges." These gauges are not vital for normal flight but are monitored or used only on as-time-allows or on a need-to-know basis. These zones are illustrated in Table 38.

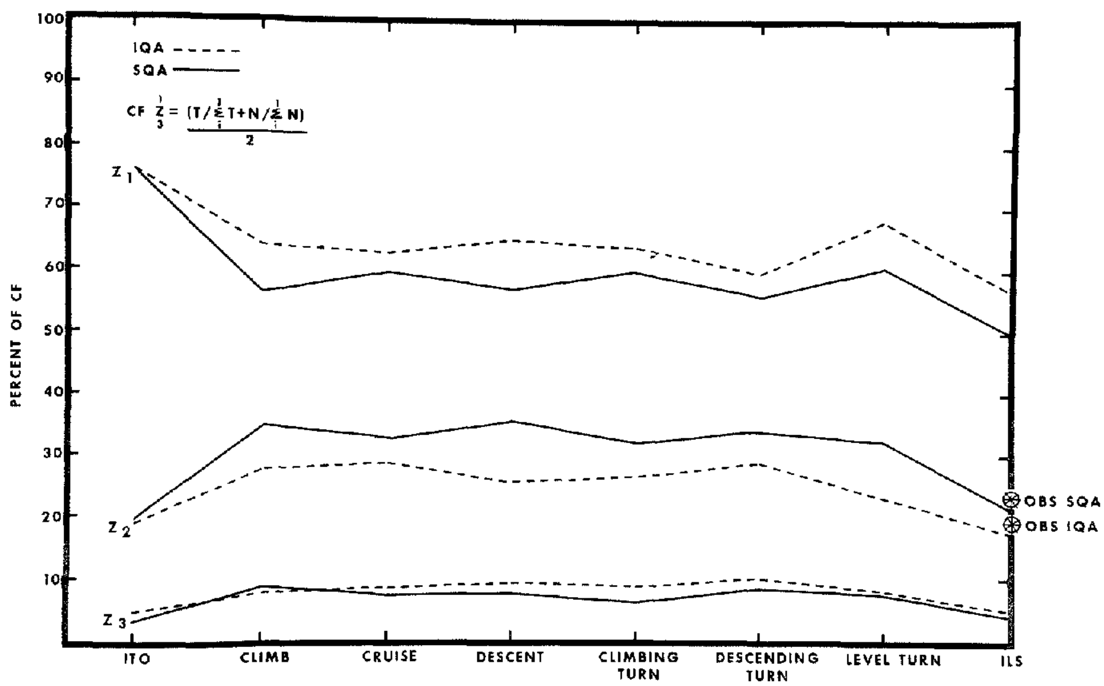
TABLE 38

INSTRUMENT CLUSTERS WITHIN EACH ZONE

ZONE I	1.	ATTITUDE INDICATOR	AH
	2.	RADIO MAGNETIC COMPASS	RMI
	3.	TURN AND SLIP INDICATOR	T&B
ZONE II	1.	ALTIMETER	ALT
	2.	AIRSPEED INDICATOR	AS
	3.	VERTICAL VELOCITY INDICATOR	VSI
ZONE III	1.	AIRCRAFT MONITORING GAUGES	TORQ, RPM, ELEC OIL, FUEL
	2.	SPECIAL NAVIGATION INSTRUMENTATION	OBS
	3.	ALL OTHER VISUAL AREAS	REST

If these zones adequately describe aviator visual performance during IFR flight in a helicopter, the twenty-three instruments utilized by the pilot have been reduced to three zones. The visual performance data from this investigation describe the percentage of lapse time, scan rate, and dwell time along with link values of these zones. However, the importance or cost of a zone or gauge can be described by the sum of the frequency that an area is visually fixated and the average time fixated in that area (dwell time). The lapse time and number of fixations on the gauges can be utilized to derive this single value. The formula would appear as: $CF_Z = (T/\Sigma T + N/\Sigma N)/2$. CF represents the "cost factor" of each zone, "T" is in seconds, and "N" is number. If this value is divided by two, the CF is in percentage of workload.

If the above formula is utilized, the data in this study can be reduced to a single value for each of the three zones across eight flight maneuvers. The CF value reflects the percentage of time, scan rate, and dwell time as one value. The only variable not accounted for is link value. This value simply represents "how well" the panel was arranged. This assumption is supported by Senders, et al.[18] A summary graph for the three zone/cost factor approach is represented by Figure 15. The solid line represents the SQA aviators and the broken line the IQA.



GRAPH OF CF/ZONE
FIGURE 15

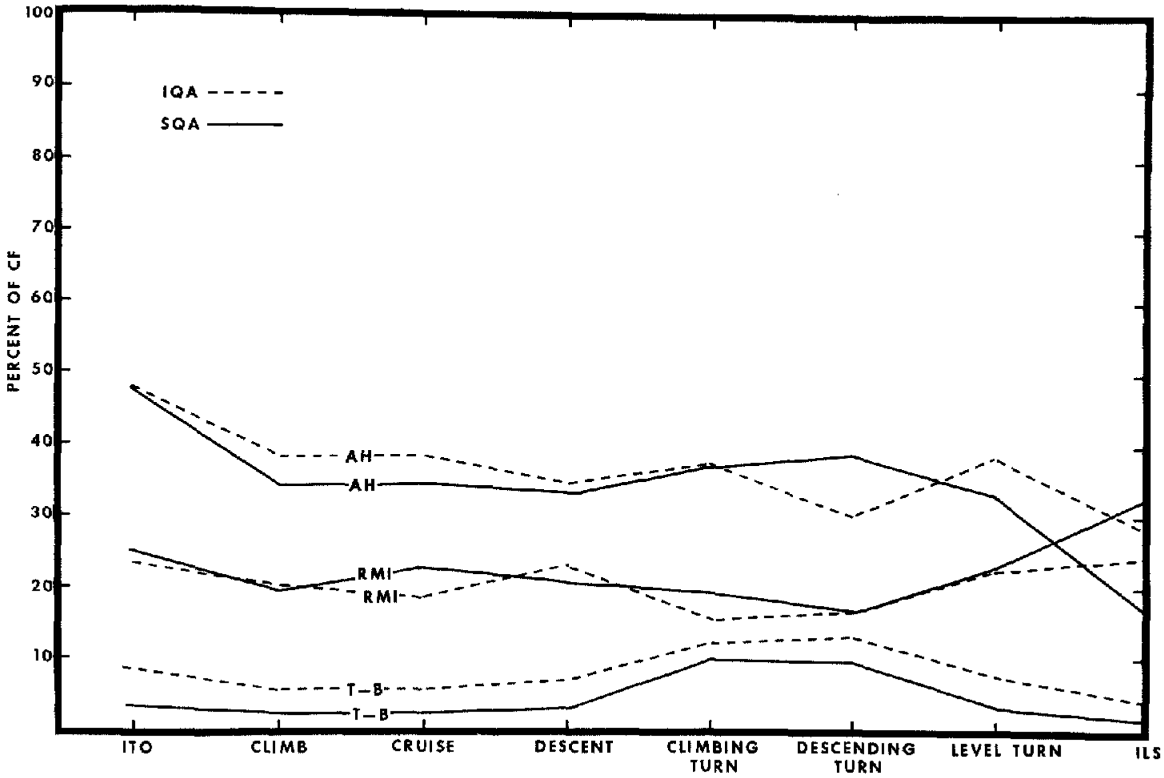
Each zone represented on the graph has a distinct level of visual work cost. Zone 1 utilizes approximately 60% of the total effort; Zone 2, 30%; and Zone 3 less than 10%. Zone 2 effort is increased only as Zone 1 decreases and Zone 3 remains fairly constant with the exception of the ILS maneuver. The reason for this observation could be that the ILS was different from all the other maneuvers in that it included not only basic flight but also a navigation problem. Zones 1 and 2 have distinct workload points for the ITO and ILS maneuvers with the rest of the maneuvers requiring some effort allotted between these two maneuvers. The ITO appears to be the least stable maneuver requiring maximum work cost within Zone 1 while during the ILS the utilization of Zone 1 is at its lowest point. Since both maneuvers are considered to be high workload situations, these values in Zone 1 could represent a maximum and minimum workload required in the zone to afford stability management of a helicopter. Notice that during these same two maneuvers Zones 2 and 3 are at the same workload levels from one maneuver to the other. This demonstrates that as workload increases, both of these areas are sacrificed.

The fact that all maneuvers other than the ITO and ILS are at a level of less than maximum effort, and more than minimum effort in Zone 1, could represent some rest time that is not essential to flight.

The statistical analysis which was previously completed supports the Zone/CF theory to a large degree. The values which comprise the CF were tested separately. The MANOVA and univariate F of the percent of lapse time, scan rate, and dwell time (CF value) found no differences between the climb, cruise, and descent maneuvers and found minimal differences when these were compared with the turn maneuvers. The major differences were found when comparing CF values of the ITO and ILS maneuvers to the "flight" maneuvers; likewise, the stepwise discriminant analysis utilizing the same three criteria could classify only the ILS and ITO with any accuracy.

The univariate F test found differences in the percent of lapse time and scan rate of altimeter, vertical speed indicator, radio magnetic compass, and the attitude indicator when comparing the climb, cruise, and descent maneuvers with the ITO. Reviewing the mean values demonstrates that the usage of the gauges in Zone 2 (ALT and VSI) was depressed while Zone 1 (AH and RMI) required more attention during the ITO. The OBS gauge was significant only during the comparison of the three flight maneuvers with the ILS. Finally, the turn's CF values were significantly different from climb, cruise, and descent because of the rearrangement of usage of the instruments within Zone 2. These conclusions are also supported by the graph in Figure 15.

The univariate F test revealed the only significant difference between subject groups was their use of the turn and slip indicator. The stepwise discriminant analysis also was able to discriminate groups mainly by their usage of this same instrument. Therefore, Zone 1 for the two groups was expanded and the results appear in Figure 16.



GRAPH OF CF/ZONE 1

FIGURE 16

The visual performance on the radio magnetic compass has varying results across groups. However, the attitude indicator (with the exception of descending turns) and the turn and bank indicator do show distinct level differences between groups. These data compared to the HIMS data in Tables 35 and 36 demonstrate that the IQA group utilized the T&B the most and had the least pedal control stability. Other investigators have explained this as a single channel response describing that a subject will monitor that area which changes the most.[18] Finally, it should be noted that with the exception of the difference of the two groups within Zone 1, their CF performance paralleled one another (Figure 15). The total visual workload of the SQA was lower in Zone 1 than the IQA, allowing the SQA more time for Zone 2 and better aircraft control. This usage of Zone 1, as other data are indicating, could reflect a major difference of proficiency levels with the SQA being the more currently proficient.

CONCLUSIONS

This study was initiated to investigate the visual performance of pilots flying during helicopter IFR maneuvers. The study of IFR maneuvers was unique because the aviators were forced by conditions to receive any and all of their visual cues to manipulate the aircraft from an instrument panel. This limited visual field allowed investigators to analyze which cues were fixated and derive what information was visually obtained by the pilot. During VFR this extraction of visual performance would be very difficult because of lack of precise definitions as to the quality of possible VFR cues.

The data reflected in Tables 6 through 17 and Figures 6 through 13 represent pilot visual performance during the various maneuvers of this project. This information is useful in itself in describing general visual performance during helicopter flight. Some conclusions can be noted from this data.

a. When compared to Fitts, Jones, and Milton's visual studies[9] in fixed wing aircraft during IFR maneuvers, it is readily apparent that the percentage of utilization of the RMI and AH are reversed during helicopter flight with the AH being utilized the most.

b. During helicopter flights the AH and RMI comprised over 50% of the total visual performance with no other instrument being utilized one-half the time of either instrument with one exception--the ILS maneuver.

c. The mean dwell time for instruments with simple pointer systems such as the AS, ALT, and VSI was 400 to 500 milliseconds while more complex instruments such as the RMI and AH required 500 to 600 milliseconds.

d. Oil, fuel and electrical gauges were each observed less than one percent of the time. If consideration is given to this fact, it can be interpreted in the sense that each aviator has less than a one percent chance of detecting any malfunction reflected by these gauges.

e. The link values reflect that the major scan pattern utilized by the helicopter pilots was to use the AH and RMI as base of visual information from which they darted out to other areas briefly and back to the base again.

f. Subject opinion data did not agree with the objective visual data.

The above results have a basic application in describing visual performance during helicopter operations. However, because of the numerous tables and figures involved it becomes extremely difficult to attempt to predict or model visual performance/workload in other aircraft or during other operational missions. To attempt to combine all the useful information into a more concise package, the visual zone/cost factor was introduced. The zones were ranked as to their visual importance to the pilot with the aircraft stability management zone being the most important. The cost factor accounted for the frequency and duration of the pilot's fixation to describe his total visual requirements. This formula provides some possible useful alternatives.

a. The usage of Zone 1 between groups of subjects could describe current proficiency differences as described in the discussion section.

b. It could also be predicted that a significant reduction in Zone 1 could be accomplished by providing a more stable helicopter platform as in fixed wing aircraft. Such a reduction would provide more visual time for other tasks such as monitoring of other gauges or attending to other mission needs. Additionally, because Zone 1 comprises over 55% of the visual workload, any visual performance reduction in this area would have significant savings in visual workload.

c. With the minimum and maximum visual workloads in Zone 1 noted for the ITO and ILS maneuvers, perhaps accidents during inadvertent instrument flight could be explained as exceeding the minimum visual workload in this zone for aircraft stability management.

This study should not conclude visual performance/workload but should assist in developing a data base for predicting visual performance/workload during flights in aircraft of varying stability and during adverse weather missions dictated by military requirements. The application of this and similar information to aircraft panel design could ultimately provide the significant factor which determines safe tactical mission accomplishment.

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APPENDIX A

Visual Performance Impressions Questionnaire

II. FREQUENCY OF USE (Cont'd)

	AIRSPEED INDICATOR	ARTIFICIAL HORIZON	ALTIMETER	RMI	VERTICAL SPEED INDICATOR	VOR	CLOCK	TURN AND BANK	MAGNETIC COMPASS
CLIMB									
1. I very often refer to this instrument.									
2. I frequently refer to this instrument.									
3. I occasionally refer to this instrument.									
4. I rarely refer to this instrument.									
5. I never refer to this instrument.									
CRUISE									
1. I very often refer to this instrument.									
2. I frequently refer to this instrument.									
3. I occasionally refer to this instrument.									
4. I rarely refer to this instrument.									
5. I never refer to this instrument.									

II. FREQUENCY OF USE

	FUEL PRESSURE	FUEL QUANTITY	ENGINE OIL	ENGINE OIL TEMP	TRANS OIL	TRANS OIL TEMP	MAIN GENERATOR	STANDBY GENERATOR	DC VOLTMETER	AC VOLTMETER	ENGINE RPM	TORQUE	GAS PRODUCER	EXHAUST TEMP
RUN-UP														
1. I very often refer to this instrument.														
2. I frequently refer to this instrument.														
3. I occasionally refer to this instrument.														
4. I rarely refer to this instrument.														
5. I never refer to this instrument.														
HOVERING														
1. I very often refer to this instrument.														
2. I frequently refer to this instrument.														
3. I occasionally refer to this instrument.														
4. I rarely refer to this instrument.														
5. I never refer to this instrument.														

II. FREQUENCY OF USE

	FUEL PRESSURE	FUEL QUANTITY	ENGINE OIL	ENGINE OIL TEMP	TRANS OIL	TRANS OIL TEMP	MAIN GENERATOR	STANDBY GENERATOR	DC VOLTMETER	AC VOLTMETER	ENGINE RPM	TORQUE	GAS PRODUCER	EXHAUST TEMP
RELIABILITY - Must be operating.														
1. I would never trust this instrument.														
2. This instrument is frequently unreliable.														
3. This instrument is as reliable as any.														
4. I normally find this instrument to be reliable.														
5. I consider this instrument highly reliable.														

I. READABILITY (Cont'd)

	FUEL PRESSURE	FUEL QUANTITY	ENGINE OIL	ENGINE OIL TEMP	TRANS OIL	TRANS OIL TEMP	MAIN GENERATOR	STANDBY GENERATOR	DC VOLTMETER	AC VOLTMETER	ENGINE RPM	TORQUE	GAS PRODUCER	EXHAUST TEMP
OPERATING RANGES														
1. Operating ranges are very often hard to distinguish accurately and quickly.														
2. Operating ranges are often hard to distinguish accurately and quickly.														
3. Operating ranges are occasionally hard to distinguish accurately and quickly.														
4. Operating ranges are rarely or seldom hard to distinguish accurately and quickly.														
5. Operating ranges are never hard to distinguish accurately and quickly.														
SCALING														
1. The scale on this instrument needs more divisions.														
2. The scale on this instrument needs fewer divisions.														
3. The scale on this instrument is satisfactory.														
4. Color coding could be improved on operating zones.														
5. This instrument could be replaced by an idiot light.														

APPENDIX B

TABLES 6 through 17

TABLE 6

PERCENT OF VISUAL LAPSE TIME (%T)

	ITO		TURN		ILS	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	50.8 (21.5)	52.5 (11.3)	34.2 (9.7)	42.9 (9.7)	15.5 (6.7)	29.8 (8.9)
RMI	23.9 (9.1)	21.5 (6.8)	24.4 (4.7)	24.0 (5.9)	34.3 (5.7)	23.7 (4.9)
T-B	3.1 (2.1)	8.0 (4.9)	3.3 (2.8)	6.4 (5.2)	1.1 (0.9)	3.8 (0.7)
ALT	6.0 (3.1)	3.9 (2.7)	10.2 (3.6)	6.9 (2.0)	5.3 (2.3)	6.3 (1.7)
A/S	8.4 (6.6)	6.5 (2.8)	11.5 (3.6)	9.6 (5.9)	5.6 (2.6)	7.4 (2.2)
VSI	3.3 (2.5)	3.4 (2.5)	7.0 (3.5)	2.4 (2.8)	6.9 (4.1)	3.7 (2.7)
OBS	0.5 (1.0)	0 0	3.9 (6.0)	2.9 (4.4)	29.6 (4.5)	20.9 (5.1)
TRQ	1.4 (1.7)	3.0 (3.9)	4.3 (3.5)	3.9 (2.5)	1.0 (1.0)	2.0 (1.3)
RPM	0 0	0	0 0	0 0	0	0.2 (0.2)
ELEC	0	0	0	0	0	0 0
OIL	0	0	0	0	0	0.2 (0.4)
FUEL	0	0	0	0	0	0
REST	2.4 (4.4)	1.1 (2.0)	1.0 (1.6)	0.9 (1.4)	0.7 (0.8)	2.0 (1.4)

TABLE 7

PERCENT OF VISUAL LAPSE TIME (%T)

	CLIMB		CRUISE		DESCENT	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	33.7 (10.8)	40.8 (9.6)	34.5 (10.1)	42.4 (8.9)	35.7 (8.0)	36.5 (8.6)
RMI	21.5 (6.0)	21.3 (6.1)	23.0 (7.2)	18.7 (5.4)	21.9 (5.3)	24.6 (6.1)
T-B	2.2 (2.3)	6.9 (4.6)	2.9 (2.4)	5.6 (3.8)	2.9 (1.1)	6.9 (2.7)
ALT	12.5 (2.9)	8.0 (2.9)	12.0 (3.1)	9.8 (4.6)	9.3 (1.5)	8.1 (3.3)
A/S	12.0 (6.1)	10.5 (5.7)	12.0 (5.8)	9.7 (5.1)	13.1 (3.9)	9.0 (4.8)
VSI	9.1 (3.2)	5.8 (2.8)	7.0 (3.5)	5.5 (4.0)	11.0 (2.2)	5.6 (2.5)
OBS	2.0 (4.7)	1.0 (1.0)	1.4 (2.7)	1.6 (3.4)	1.3 (1.1)	1.7 (1.5)
TRQ	4.5 (4.0)	3.9 (2.7)	4.2 (3.4)	5.5 (3.3)	3.8 (3.5)	5.0 (1.4)
RPM	1.1 (1.8)	0.2 (0.3)	0.7 (0.9)	0.3 (0.5)	0.4 (0.4)	0.1 (0.2)
ELEC	0	0	0	0	0	0.2 (0.3)
OIL	0	0.1 (0.2)	0 0	0 0	0	0.2 (0.4)
FUEL	0		0.5 (1.4)	0	0	0.1 (0.2)
REST	1.4 (1.5)	1.5 (1.7)	0.9 (1.4)	0.9 (1.0)	0.6 (0.5)	2.0 (2.0)

TABLE 8

PERCENT OF VISUAL FIXATIONS (%N)

	ITO		TURN		ILS	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	40.5 (6.2)	38.4 (10.0)	31.9 (8.0)	34.9 (8.1)	18.9 (7.5)	27.7 (8.1)
RMI	28.8 (5.2)	25.1 (5.8)	22.4 (7.5)	22.2 (4.8)	30.0 (2.1)	24.1 (2.7)
T-B	4.0 (1.6)	8.4 (5.8)	2.9 (2.2)	7.2 (4.8)	1.9 (1.3)	4.2 (1.3)
ALT	8.6 (5.3)	6.4 (2.6)	12.3 (2.8)	9.8 (2.7)	6.1 (2.5)	7.2 (1.7)
A/S	9.5 (3.9)	11.0 (3.)	13.7 (3.7)	13.8 (5.3)	7.6 (3.3)	9.4 (2.4)
VSI	4.9 (2.9)	4.6 (4.7)	8.5 (5.6)	3.6 (3.5)	8.8 (5.0)	4.6 (3.2)
OBS	0.3 (0.5)	0 0	3.3 (5.7)	3.1 (3.1)	24.3 (4.1)	18.6 (3.5)
TRQ	1.8 (1.6)	3.6 (2.5)	3.5 (2.3)	3.3 (1.5)	1.3 (1.2)	2.0 (1.3)
RPM	0 0	0	0 0	0 0	0.1 (0.2)	0.2 (0.8)
ELEC	0	0	0	0	0	0 0
OIL	0	0	0	0	0	0.1 (0.2)
FUEL	0	0	0	0	0	0
REST	1.2 (2.4)	2.3 (2.3)	1.0 (2.6)	1.9 (2.7)	0.9 (1.2)	1.9 (1.6)

TABLE 9

PERCENT OF VISUAL FIXATIONS (%N)

	CLIMB		CRUISE		DESCENT	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	33.9 (8.2)	35.8 (8.6)	34.8 (5.1)	36.3 (9.6)	32.3 (5.1)	33.7 (9.2)
RMI	18.4 (4.8)	19.2 (5.4)	20.7 (5.6)	18.0 (5.2)	20.0 (4.6)	21.5 (6.1)
T-B	2.7 (2.5)	5.4 (3.8)	2.4 (2.2)	5.6 (3.5)	3.1 (1.2)	7.4 (4.1)
ALT	12.1 (3.6)	9.8 (3.0)	13.5 (3.8)	11.7 (5.3)	10.4 (1.9)	8.1 (2.4)
A/S	13.8 (6.6)	13.6 (4.8)	14.2 (4.8)	13.8 (5.7)	14.8 (4.0)	12.8 (5.7)
VSI	10.2 (4.7)	7.5 (3.8)	7.2 (5.3)	6.6 (4.4)	11.9 (3.8)	7.3 (4.0)
OBS	1.9 (3.7)	1.6 (1.4)	1.6 (2.3)	1.6 (2.6)	2.3 (1.5)	2.2 (1.8)
TRQ	4.0 (2.8)	4.2 (2.4)	3.0 (2.7)	5.0 (2.3)	3.7 (2.5)	4.1 (0.8)
RPM	1.0 (1.3)	0.5 (0.5)	0.6 (0.6)	0.3 (0.6)	0.5 (0.4)	0.1 (0.1)
ELEC	0	0	0	0	0	0.1 (0.2)
OIL	0	0.1 0.1	0 0	0 0	0	0.2 (0.3)
FUEL	0	0	0.4 (0.7)	0	0	0.1 (0.2)
REST	2.1 (2.6)	2.1 (2.3)	1.4 (2.9)	1.1 (0.8)	0.9 (0.7)	2.2 (1.9)

TABLE 10

VISUAL DWELL TIME IN MILLISECONDS ($\overline{X}$)

	ITO		TURN		ILS	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	920 (850)	840 (580)	570 (340)	790 (580)	510 (370)	680 (460)
RMI	600 (370)	550 (270)	580 (310)	670 (420)	680 (490)	620 (390)
T-B	520 (130)	670 (160)	560 (200)	590 (210)	410 (100)	620 (350)
ALT	450 (170)	420 (180)	480 (210)	450 (180)	550 (230)	520 (270)
A/S	580 (380)	400 (190)	480 (250)	410 (160)	480 (260)	490 (280)
VSI	530 (70)	440 (120)	470 (160)	260 (80)	470 (200)	410 (190)
OBS	250 (20)	0 0	270 (60)	330 (90)	750 (460)	720 (350)
TRQ	260 (110)	460 (150)	710 (130)	660 (190)	300 (140)	600 (320)
RPM	0 (0)	0	0 0	0 (0)	0	510 (40)
ELEC	0	0	0	0	0	70 (0)
OIL	0	0	0	0	0	290 (30)
FUEL	0	0	0	0	0	0
REST	300 (180)	130 (50)	160 (40)	170 (30)	310 (100)	500 (320)

TABLE 11

VISUAL DWELL TIME IN MILLISECONDS ($\overline{X}$)

	CLIMB		CRUISE		DESCENT	
	SQA	IQA	SQA	IQA	SQA	IQA
AH	660 (470)	740 (420)	670 (440)	790 (480)	630 (400)	690 (440)
RMI	730 (430)	680 (370)	750 (450)	690 (390)	602 (330)	760 (410)
T-B	510 (200)	740 (240)	650 (370)	670 (240)	650 (300)	670 (270)
ALT	660 (330)	530 (250)	590 (280)	550 (230)	540 (230)	620 (300)
A/S	540 (270)	510 (250)	520 (270)	490 (200)	570 (320)	440 (180)
VSI	620 (250)	500 (180)	550 (210)	480 (260)	580 (220)	500 (180)
OBS	240 (100)	260 (50)	240 (100)	300 (80)	370 (150)	330 (150)
TRQ	740 (250)	570 (320)	630 (350)	700 (260)	520 (210)	800 (390)
RPM	410 (70)	140 (20)	360 (100)	110 (30)	260 (100)	140 (0)
ELEC	0	0	0	0	0	190 (20)
OIL	0	120 (10)	0 (0)	0 (0)	0	160 (30)
FUEL	0	0	170 (60)	0	0	220 (10)
REST	290 (90)	300 (70)	210 (50)	370 (100)	350 (80)	550 (230)

TABLE 12

VISUAL LINK VALUES DURING ITO

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
	SQA		2				1			1				
REST	IQA		1	3			4	1						
	SQA	2		5			5	13	1					
ALT	IQA	6		3			6	7	3					
	SQA		4				1	9	1					
VSI	IQA				1		2	12	1	1				
	SQA							1						
OBS	IQA			1										
	SQA						3	6	3					
T-B	IQA	1					8	19	4					
	SQA		5	2	1	9		68	6	2				
RMI	IQA	1	7	2		15		66	5					
	SQA	2	15	8		3	78		20					
AH	IQA	1	16	9		15	73		25	5				
	SQA		2	1			2	23		3				
AS	IQA					2	4	30			7			
	SQA					1		4			1			
TORQ	IQA					1		7	5					
	SQA													
RPM	IQA													
	SQA													
ELEC	IQA													
	SQA													
OIL	IQA													
	SQA													
FUEL	IQA													

TABLE 13

VISUAL LINK VALUES DURING CLIMB

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
REST	SQA		10	25	4		3	9	4	1				1
	IQA		6	2			4	13	2					
ALT	SQA	30		115	4	3	21	138	27	4				
	IQA	30		45	2	1	30	172	18	1				
VSI	SQA	7	69		6	4	34	135	34	6				
	IQA	9	33		14	2	40	82	10	2				
OBS	SQA	3		4		7	30	5	1					
	IQA			3		15	21	5						
T B	SQA	1	4	6	7		9	30	17	6				
	IQA	1	4	4	5		44	79	18	6				
RMI	SQA	6	39	34	28	24		356	34	9	2			
	IQA	5	53	34	17	69		332	46	12				
AH	SQA	5	145	87	6	24	390		260	24				
	IQA	10	195	84	5	48	385		248	38	4		1	1
AS	SQA	3	62	24	1	9	34	196		52	15			
	IQA	3	7	6		18	30	235		61	3			
TORQ	SQA	1	12	2		7	9	61	13					
	IQA	1	4	5		5	11	73	47		8		1	
RPM	SQA	1				1	1	9	5	12	12			
	IQA					1	1	4	5	3				
ELEC	SQA													
	IQA						2		1					1
OIL	SQA							1						
	IQA											1		
FUEL	SQA									1				
	IQA											1		

TABLE 14

VISUAL LINK VALUES DURING LEVEL FLIGHT

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
REST	SQA		4	9			1	4	1					
	IQA		2	4	1		3	5	1					
ALT	SQA	5		55		1	34	90	18	5				
	IQA	6		26	1	1	12	91	9	1				
VSI	SQA	3	28		2		8	34	6	5				
	IQA	2	15		1	4	11	34	4	1				
OBS	SQA	1	1	1		2	2	8	3	1				
	IQA	1	1			3	7	7	3					
T-B	SQA				2		12	15		2	1			
	IQA	1	3	1	3		17	35	5	7	1			
RMI	SQA	3	23	6	12	10		240	32	3	1			2
	IQA	3	12	17	7	33		130	18	2				
AH	SQA	4	96	11	3	12	238		173	6	1			
	IQA	1	104	19	7	22	159		121	25				
AS	SQA		49	5		1	36	129		16	3			2
	IQA	1	7	3		3	11	124		27	2			
TORQ	SQA	2	5	2		1	3	20	4		5			1
	IQA		4	3	1	5	3	26	20		1		1	
RPM	SQA	1							4	4			1	1
	IQA							1	1	2				
ELEC	SQA													
	IQA													
OIL	SQA							3						3
	IQA							1						
FUEL	SQA							3	1				5	
	IQA													

TABLE 15

VISUAL LINK VALUES DURING DESCENT

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
REST	SQA		4	4		1	1	1	1	1				
	IQA		5	6	2		4	12	1	1				
ALT	SQA	3		77	3	3	13	48	7					
	IQA	6		17	1	1	13	70	7	2				
VSI	SQA	6	40		2	2	22	63	24	3				
	IQA	6	32		3	2	21	34	7	1				
OBS	SQA	2	1	4		6	15	7	2					
	IQA	1		2		10	11	8	1					
T-B	SQA		2	2	8		13	11	20	1				
	IQA	3	3	6	4		40	35	11	5	1		1	
RMI	SQA	1	18	17	15	18		200	27	1	1			
	IQA	10	19	23	11	55		170	17	7				
AH	SQA		57	60	4	7	210		139	6				
	IQA	4	53	44	9	24	214		132	13				
AS	SQA		28	16	3	1	26	110		39	1			
	IQA		7	7	1	11	6	128		29				
TORQ	SQA		4	4	2	3	2	19	13		5			
	IQA		1	2	1	5	4	32	10		1		1	
RPM	SQA		1					4	2					
	IQA				1				1					
ELEC	SQA													
	IQA	1											1	
OIL	SQA								1					2
	IQA													
FUEL	SQA													
	IQA											2		

TABLE 16

VISUAL LINK VALUES DURING LEVEL TURN

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
REST	SQA			3			4	1						
	IQA		2		1			6						
ALT	SQA	1		38		2	7	38	9	2				
	IQA	2		6	1	2	4	17	3	2				
VSI	SQA	4	19		3	1	12	14	8	5				
	IQA	2	4		1		3	6	2	1				
OBS	SQA			2		1	16	7	3					
	IQA					3	3	3						
T-B	SQA			1	1		5	10	3	2				
	IQA		1	3	3		12	16	9	1				
RMI	SQA		9	6	19	5		118	11	2	1			
	IQA	1	3	10	3	15		59	8					
AH	SQA		49	12		8	102		74					
	IQA		21			15	60		45	3				
AS	SQA		14	4		6	21	40		13	3			
	IQA		7	1		5	9	39		7	1			
TORQ	SQA	2					4	15	1					
	IQA		3			1	3	4	2					
RPM	SQA													
	IQA							1		3				
ELEC	SQA													
	IQA													
OIL	SQA													
	IQA													
FUEL	SQA													
	IQA													

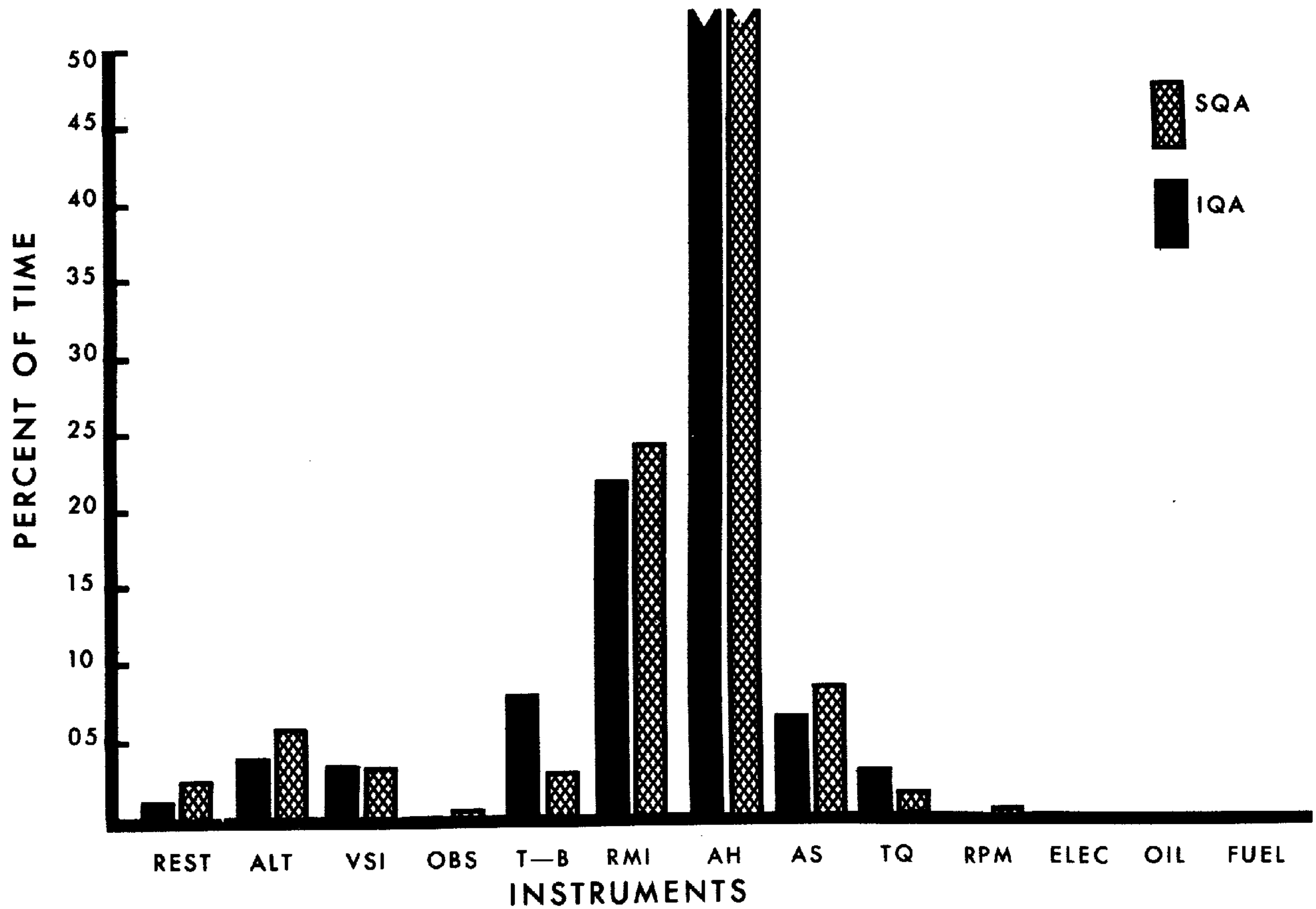
TABLE 17

VISUAL LINK VALUES DURING ILS

Previous Zone / Current Zone		REST	ALT	VSI	OBS	T-B	RMI	AH	AS	TORQ	RPM	ELEC	OIL	FUEL
REST	SQA		4	4	2		6		1					
	IQA		6	13	11	1	4	5	1					
ALT	SQA	5		37	12		24	24	8	1				
	IQA	12		17	15	1	25	81	11					
VSI	SQA	7	21		46	1	46	20	14	4				
	IQA	6	29		25	1	10	23	9					
OBS	SQA	3	10	35		17	240	123	7	2				
	IQA	11	10	20		26	186	153	10					
T-B	SQA		1	5	8		13	2	5	1				
	IQA		3	1	25		30	44	8	3				
RMI	SQA	2	23	32	324	11		116	30	4				
	IQA	6	17	14	265	31		187	15	2		1		
AH	SQA		22	33	37	1	179		68	1				
	IQA	3	86	30	62	20	257		148	14				
AS	SQA		29	11	7	5	27	45		10	2			
	IQA	3	12	5	9	10	25	118		26	3			
TORQ	SQA		1	2	1		4	12	4					
	IQA			2	1	3	4	26	8		1			
RPM	SQA								1	1				
	IQA			1		1			2					
ELEC	SQA													
	IQA													1
OIL	SQA													
	IQA													
FUEL	SQA													
	IQA												1	

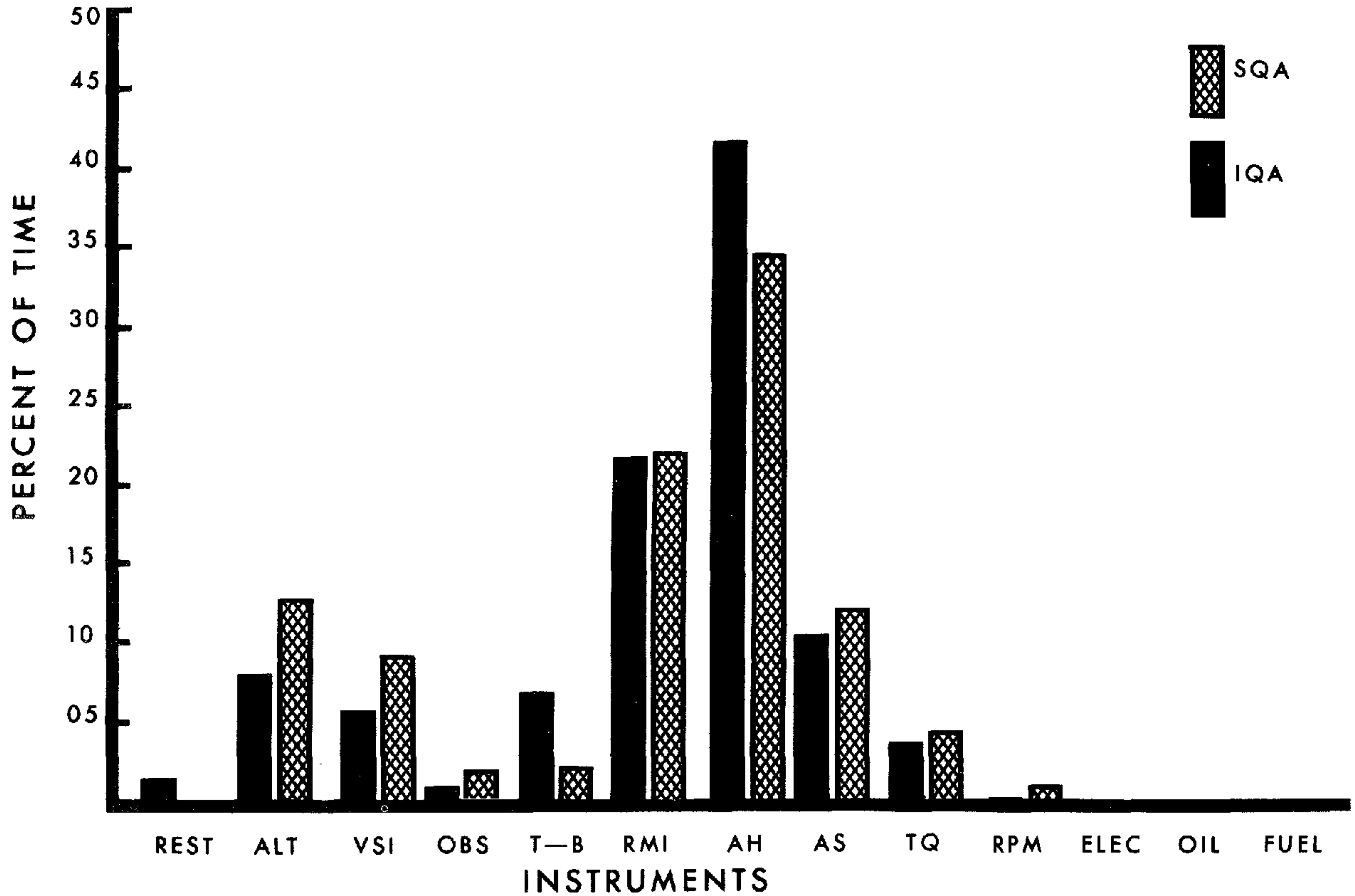
APPENDIX C

FIGURES 6 through 13



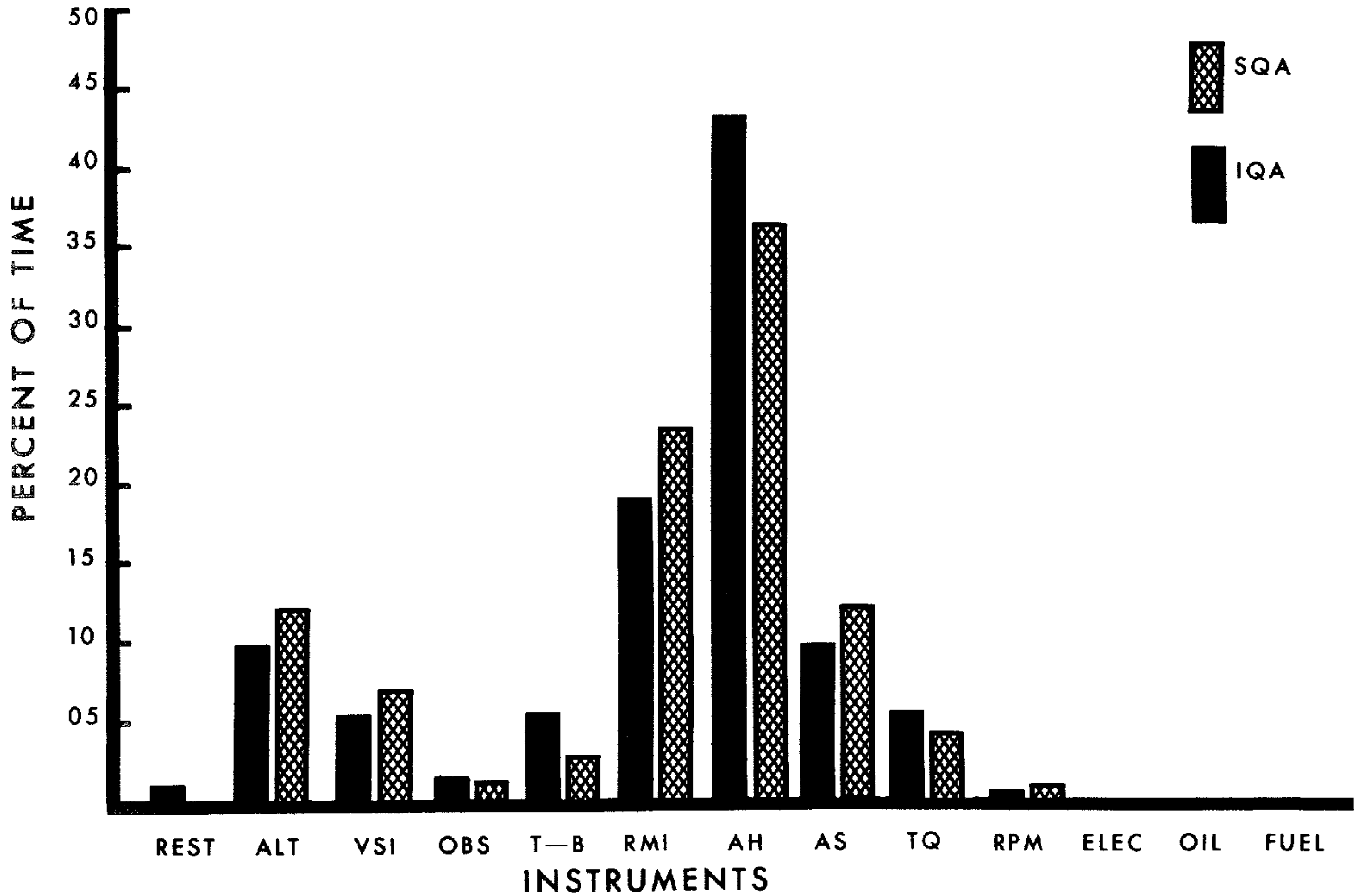
FREQUENCY OF FIXATIONS DURING ITO

FIGURE 6

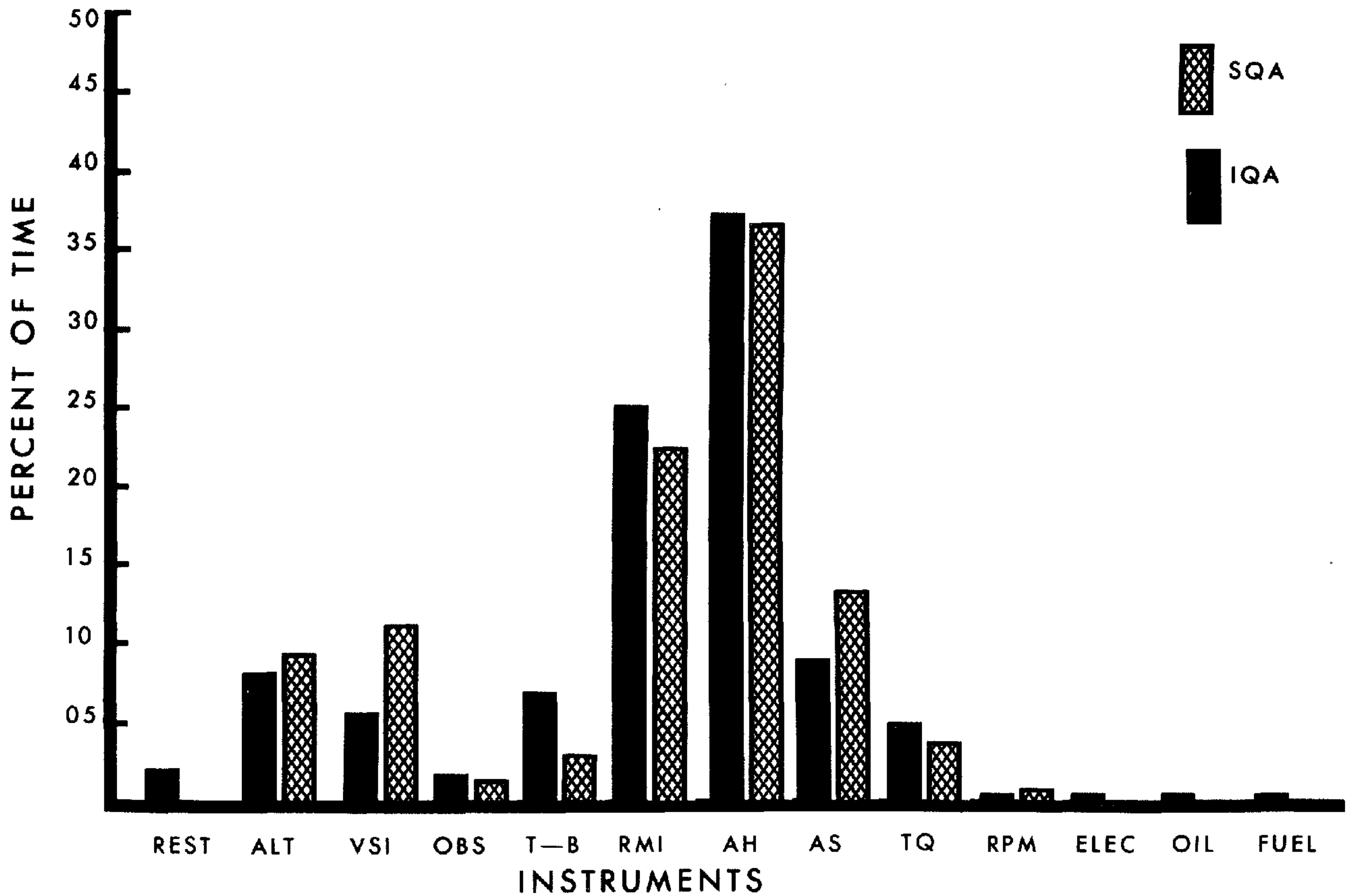


FREQUENCY OF FIXATIONS DURING CLIMB
FIGURE 7

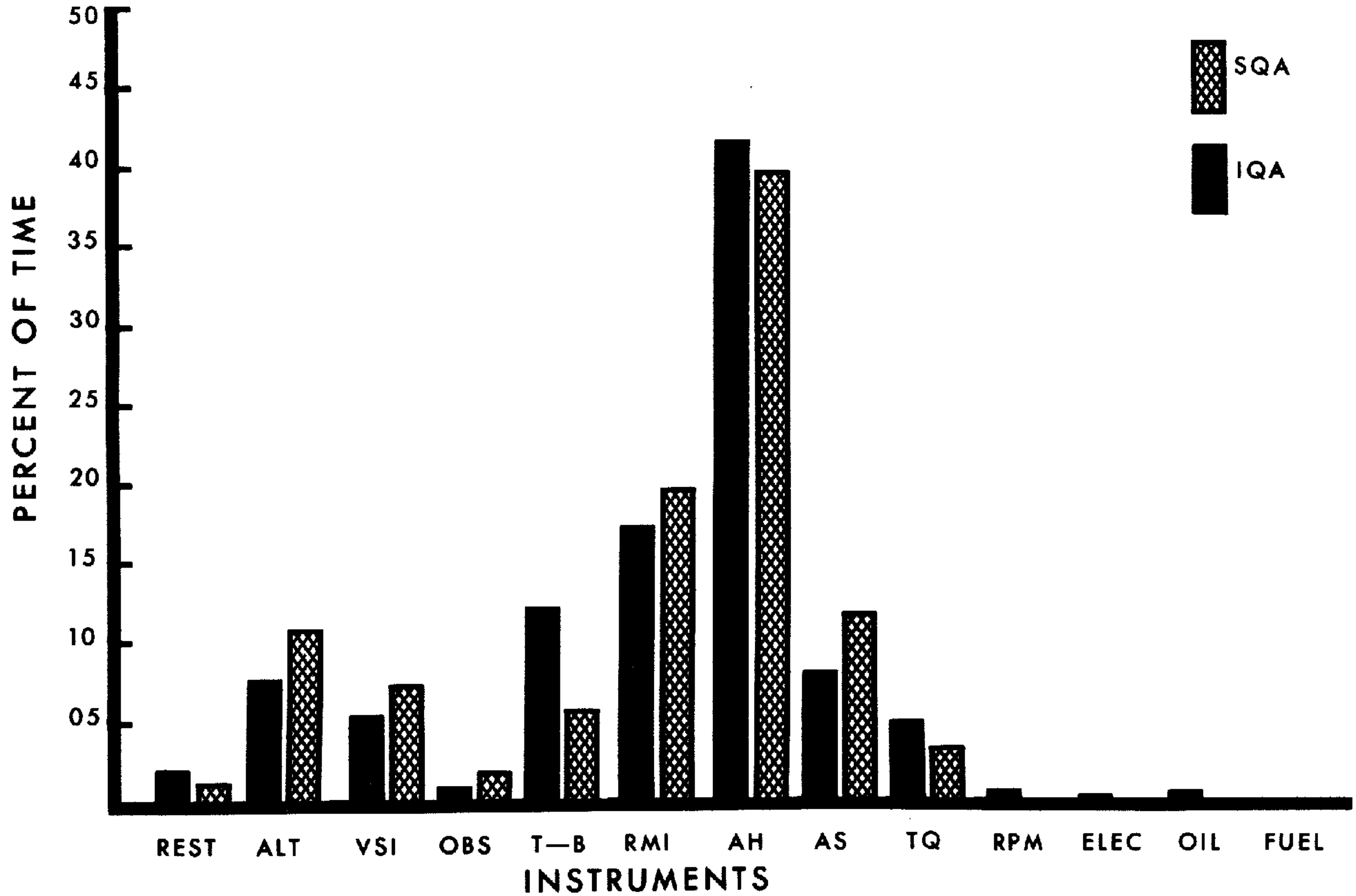
C3



FREQUENCY OF FIXATIONS DURING CRUISE
FIGURE 8

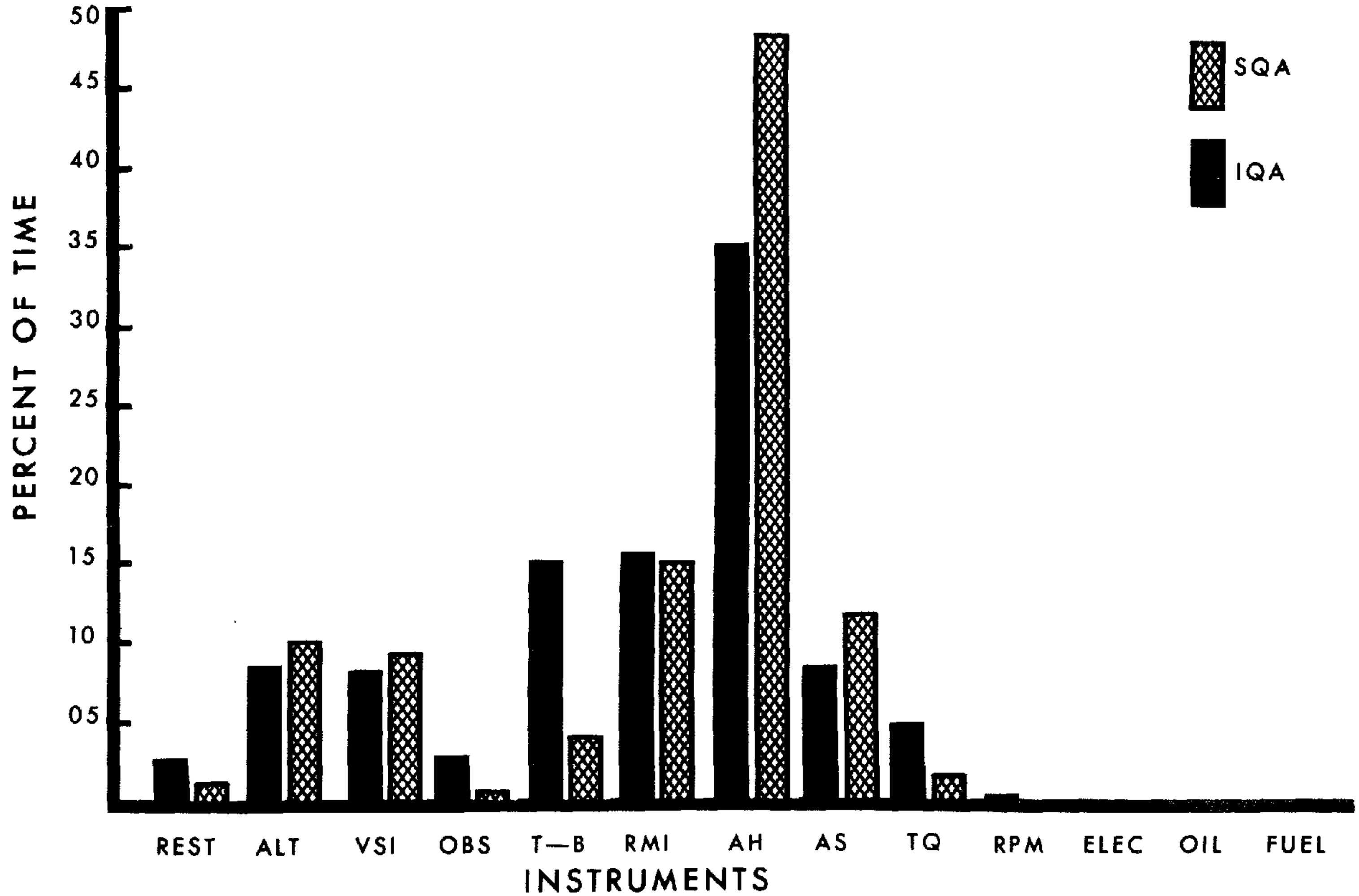


FREQUENCY OF FIXATIONS DURING DESCENT
FIGURE 9



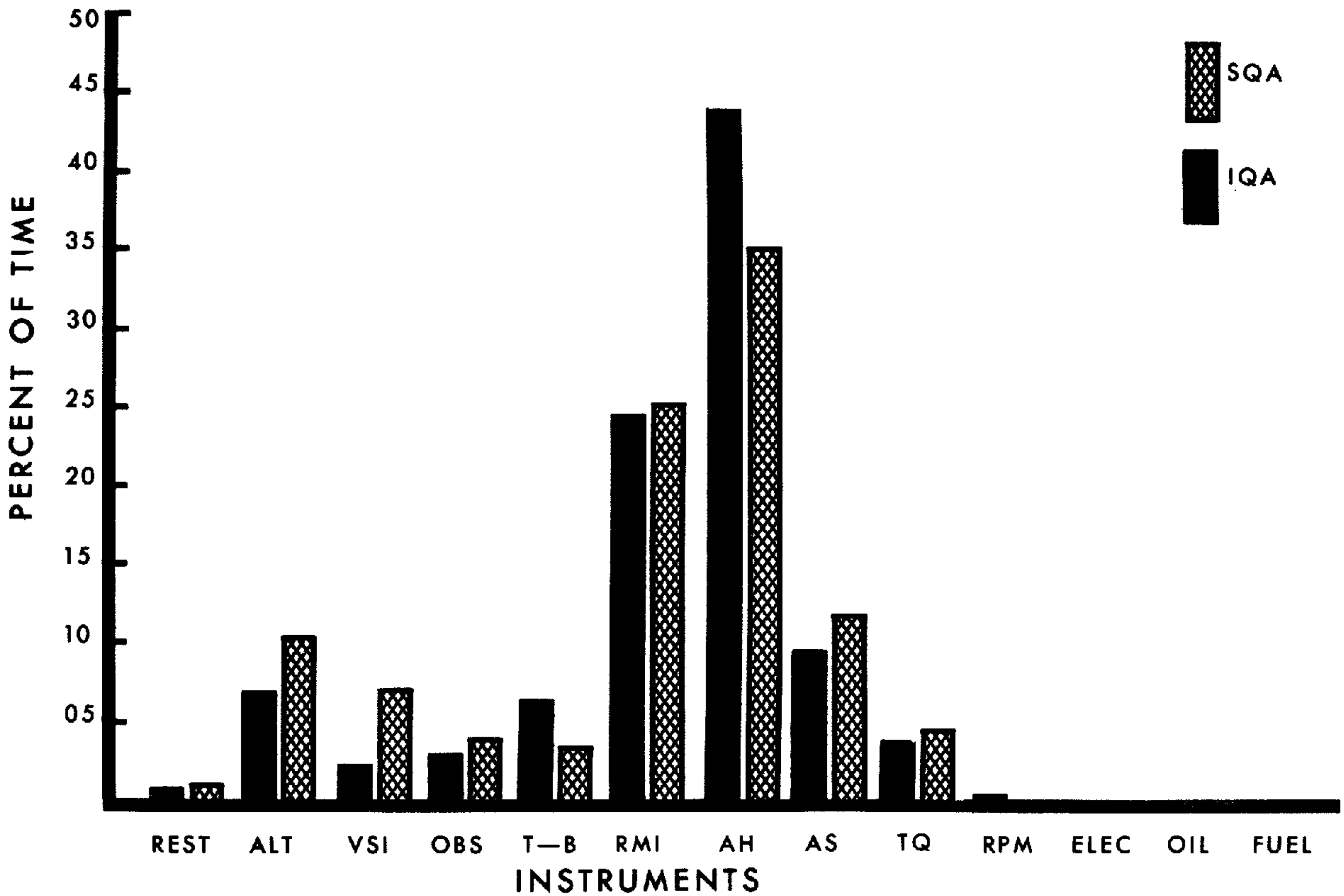
FREQUENCY OF FIXATIONS DURING CLIMBING TURN

FIGURE 10

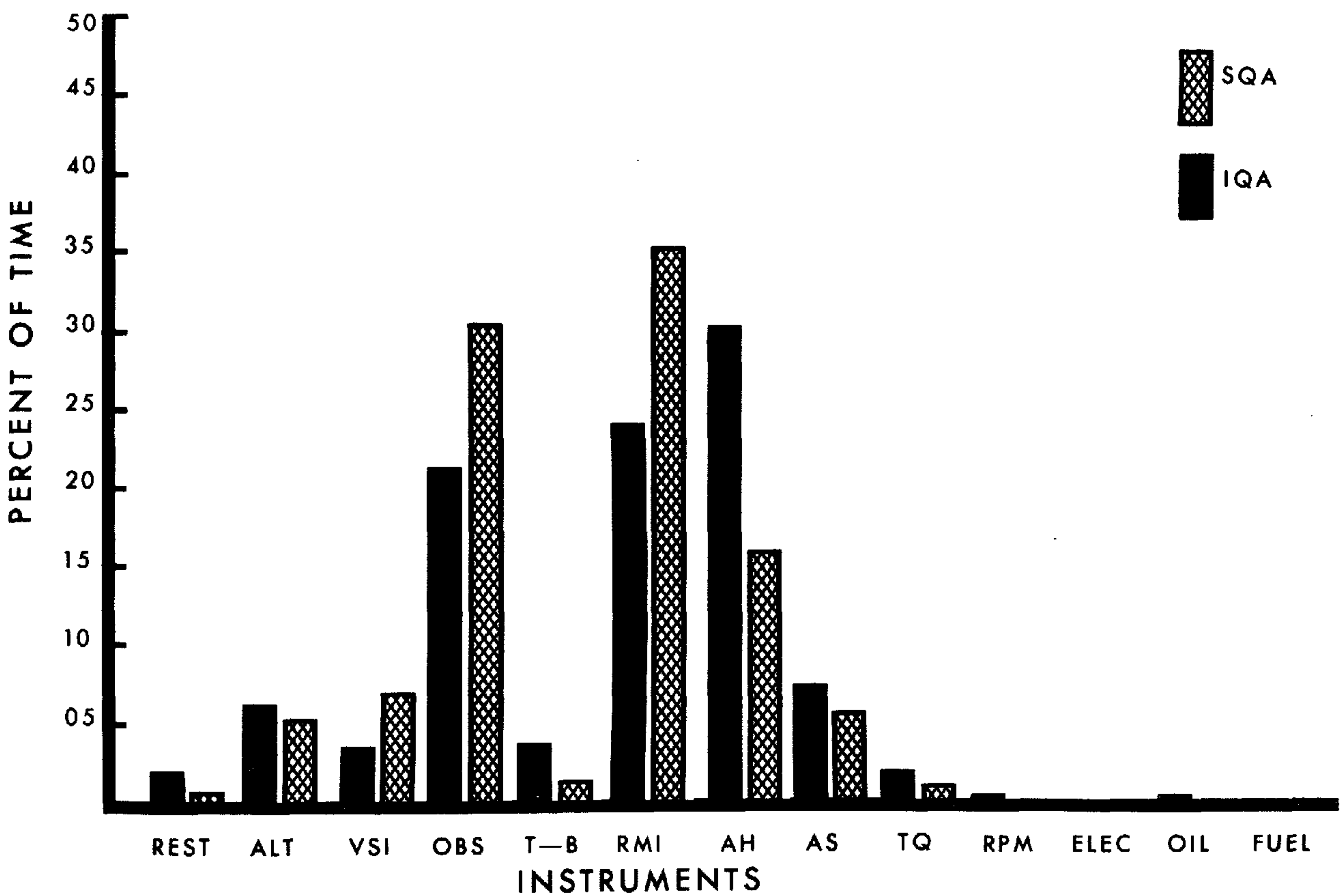


FREQUENCY OF FIXATIONS DURING DESCENDING TURN

FIGURE 11



FREQUENCY OF FIXATIONS DURING LEVEL TURN
FIGURE 12



FREQUENCY OF FIXATIONS DURING ILS
FIGURE 13