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PILOT OPINION OF FLIGHT DISPLAYS AND MONITORING GAUGES IN THE UH-1 HELICOPTER

ARMY AEROMEDICAL RESEARCH LABORATORY

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PILOT OPINION OF FLIGHT DISPLAYS AND MONITORING GAUGES IN THE UH-1 HELICOPTER

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April 1976

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Subjective responses were acquired from 54 Army aviators concerning the UH-1 instrument panel. The aviator subjects were drawn from three experience levels: student, "tac-ticket," and fully instrument rated pilots. They were asked to rank instruments with regard to frequency of use, order of preference, reliability and readability. The instruments were divided into flight displays and monitoring gauges. Ranks were requested for various profiles and flight conditions. Data analyses examined the amount of agreement between experience levels as well as

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the rankings concerning the areas mentioned above. It was determined that all experience levels were in high agreement with regard to their opinions concerning the frequency with which they used the various monitoring gauges and flight displays while hovering, climbing, cruising, and descending in both IFR and VFR conditions. The flight displays thought to be most often used were the airspeed indicator followed by the altimeter. For the monitoring gauges, engine RPM and the gas producer were ranked 1 and 2 respectively for frequency of use.

SUMMARY

Subjective responses were acquired from 54 Army aviators concerning the UH-1 instrument panel. The aviator subjects were drawn from three experience levels: student, "tac-ticket," and fully instrument rated pilots. They were asked to rank instruments with regard to frequency of use, order of preference, reliability and readability. The instruments were divided into flight displays and monitoring gauges. Ranks were requested for various profiles and flight conditions. Data analyses examined the amount of agreement between experience levels as well as the rankings concerning the areas mentioned above. It was determined that all experience levels were in high agreement with regard to their opinions concerning the frequency with which they used the various monitoring gauges and flight displays while hovering, climbing, cruising, and descending in both IFR and VFR conditions. The flight displays thought to be most often used were the airspeed indicator followed by the altimeter. For the monitoring gauges, engine RPM and the gas producer were ranked 1 and 2 respectively for frequency of use.

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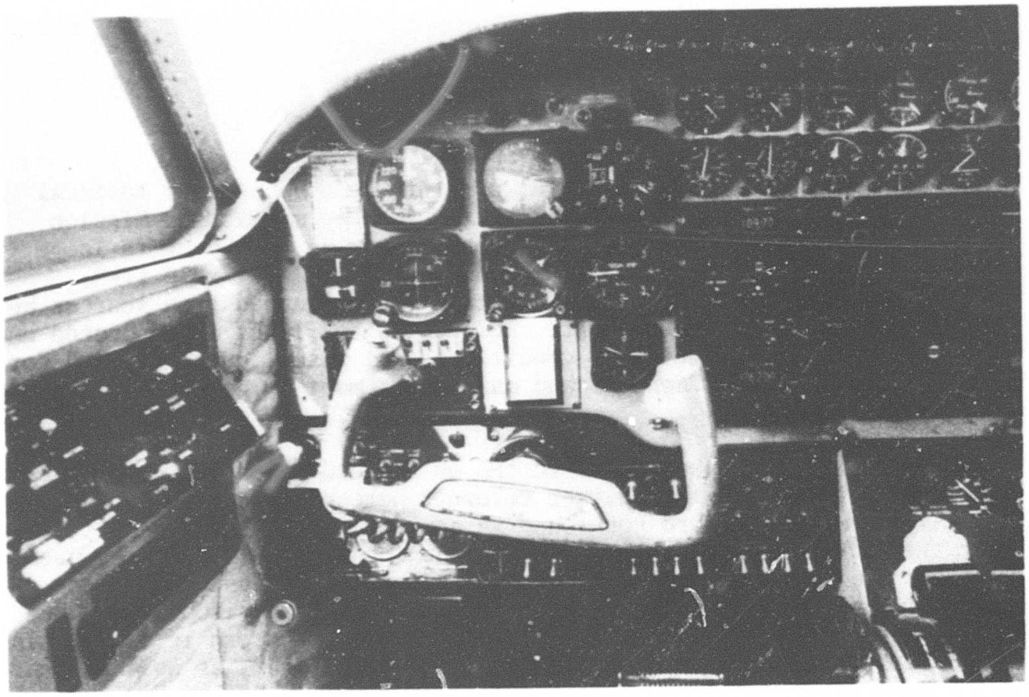
INTRODUCTION

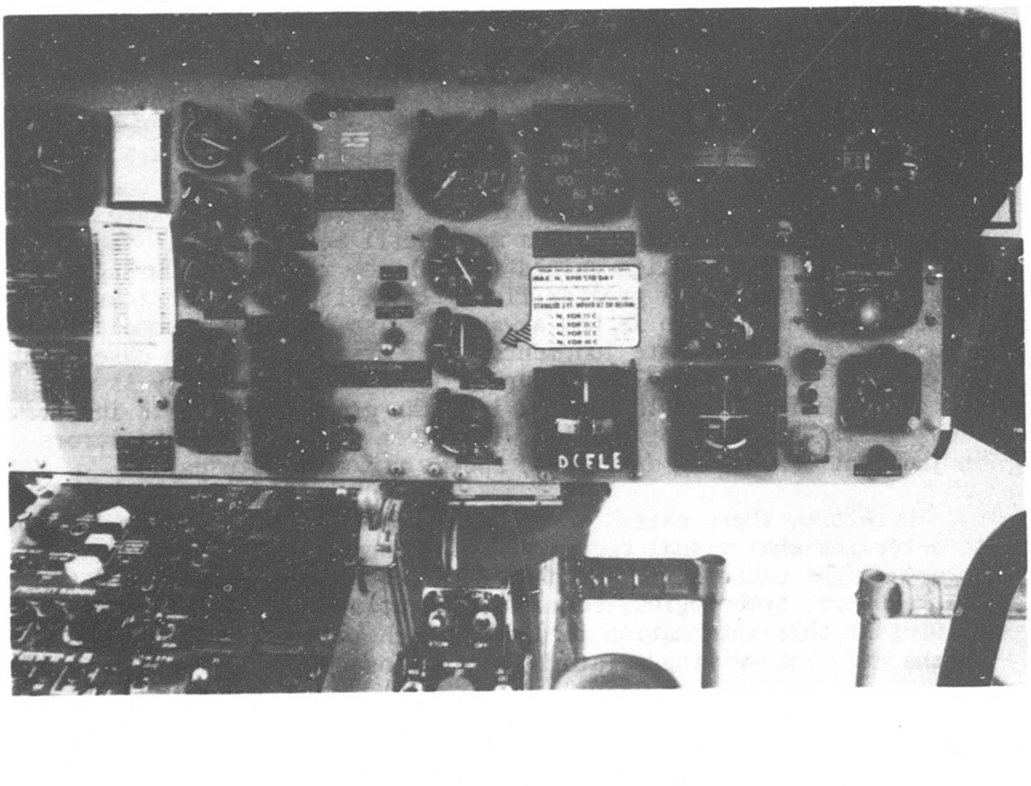
The helicopter is an integral part of the U. S. Army's tactical structure and is continuing to receive expanded missions. Mission accomplishment in a safe and efficient manner is dependent in large measure upon visual information. Under visual flight rule (VFR) conditions, required visual information can be gained from sources both inside and outside the cockpit. However, when flight is conducted under instrument flight rule (IFR) conditions, all visual cues required for appropriate aircraft control and management must be gained from inside the cockpit.

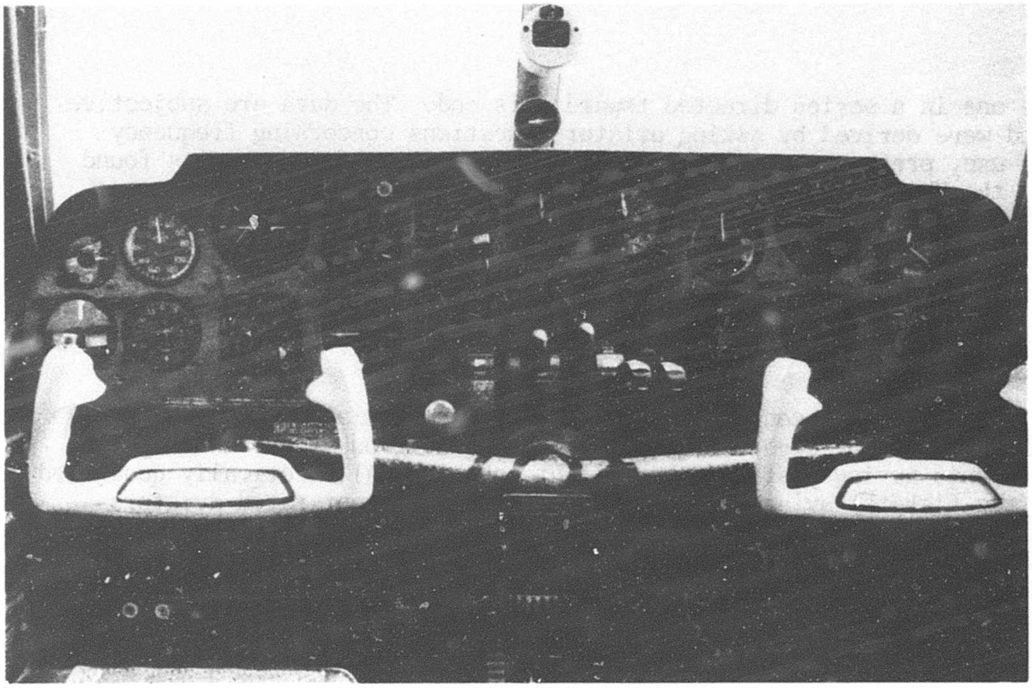
In light of the accidents in IFR or reduced visibility conditions,[1] it can be concluded that either relevant perceptual cues which exist outside the cockpit are not found in any form within the cockpit; or the information is present within the cockpit, but cannot be used effectively; or both. It is quite likely that the last situation is reflective of the true state of affairs. Such a situation is due in large measure to the paucity of research and concern in determining what information is essential for rotary wing flight, as well as how it could be displayed in a man-compatible form. What has happened for the most part is the direct transfer of fixed wing instruments and instrument arrangements (see Figure 1-4) to the helicopter without much consideration to the differences which exist in flight dynamics, controls and flight envelopes. In view of these differences, and the accident records, it would appear that this area needs emphasis.

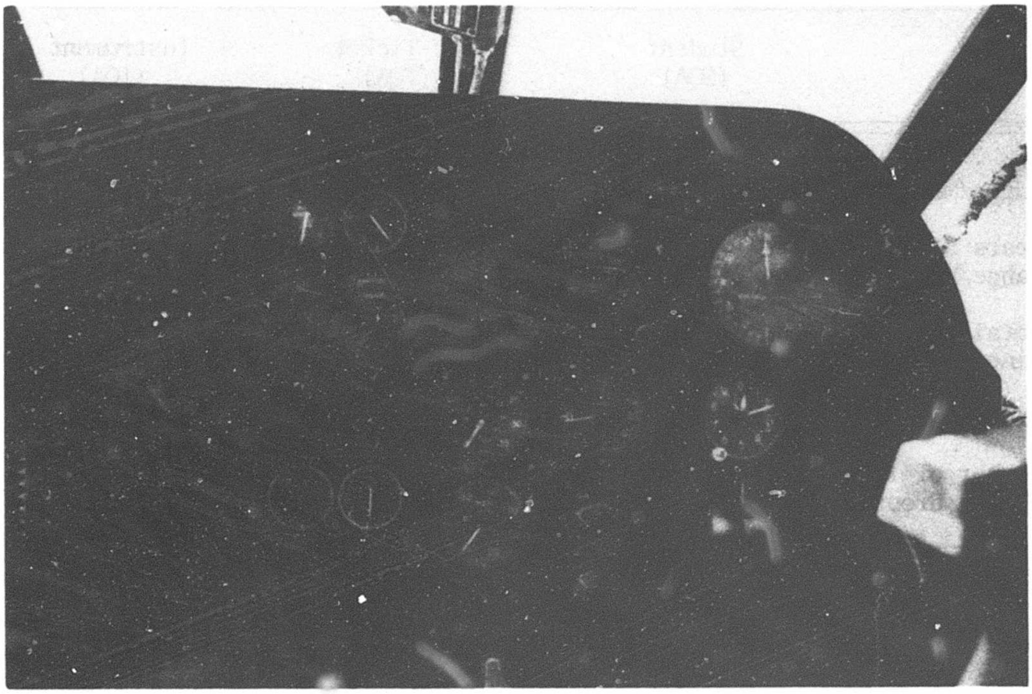
It must be pointed out that optimal rotary wing flight during IFR and reduced visibility conditions is not likely to be achieved simply by providing the outside world in the cockpit via a contact display. The basic question of what cues are required for safe flight and how to correctly display them must still be addressed. Though the additional information gained through the windscreen during rotary wing VFR flight permits greater flexibility, it too has serious problems in that the information is not always precise enough nor complete enough to permit accurate judgments. If this were not the case most mid-air collisions would not occur on days where visibility is not a problem, aviators would not fly into the ground when it is in good view, and they would not collide with other obstacles due to errors in judgment concerning distances, speeds and/or attitudes.

Therefore, there exists the need, independent of visual conditions, to determine what visual cues are used and needed to achieve maximum rotary flight capability. Secondly, there exists the need to determine what sensors, symbologies, formats and display types are then required to present this information in a form which is compatible for use by the Army rotary wing aviator. The purpose of this investigation









is one in a series directed toward this end. The data are subjective and were derived by asking aviators questions concerning frequency of use, preference, reliability and readability of instruments found in the UH-1 helicopter.

METHOD

Subjects

The subjects consisted of fifty-four Army aviators divided into three groups of eighteen subjects each. The groups were made up of students having just finished flight school (SQA), tactically qualified ("tac-ticket") aviators (TQA), and fully instrument rated aviators (IQA). Demographic information concerning subjects within each group is presented in Table 1.

Table 1

Biographical Sketch of Subjects

	Student (SQA)	Tac-Ticket (TQA)	Instrument (IQA)
Age - Range/Mean	21-30/23	20-27/23	24-55/34
Years Service - Range/Mean	1-9/2	1-9/3	4-22/16
Total Flight Time - Mean	200	1300	3500
A/C Flown Most	UH-1	UH-1	UH-1
Number of IP Within Group	0	15	15

Questionnaire

The questionnaire was divided into five parts--Biographical Data, Frequency of Use, Order of Preference, Reliability, and Readability. Questions were asked concerning the fourteen monitoring gauges and nine flight displays found in the UH-1 helicopter. Examples from the questionnaire can be seen in Appendix A.

Procedures

The questionnaire was administered to the subjects on a group basis. Each group was instructed to consider both VFR and IFR conditions when answering the questions ranking Frequency of Use, Reliability, and Readability. When considering Order of Preference, they were to consider only VFR conditions. The subjects were asked in these questions to compare fourteen monitoring gauges and nine flight instruments.

(a) Frequency of Use

For the Frequency of Use comparisons, six flight segments were considered. These were: Run-up, Hovering, Pre-Takeoff, Climb, Cruise and Descent. Definitions of these profiles can be found in Table 2. Each individual instrument was to be considered under each of the flight profiles and given a rating from 1 (indicating that they often referred to the instrument) to a rating of 5 (indicating that they never referred to the instrument.) Ratings were not to reflect the perceived importance of the instrument, but rather the amount of time the instrument was used.

Table 2

Definitions of Frequency of Use Profile

Profile	Definition
Run-up	Time from engaging starter switch to flight idle.
Hover	Three-foot taxiing of aircraft to take off point.
Pre-Take Off	Pre-take off check as outlined in Operator's Manual.
Climb	Straight climb in either VFR or IFR conditions.
Cruise	Level flight, VFR or IFR, with no descent or climb.
Descent	Straight descent in either VFR or IFR conditions.

(b) Order of Preference

The Order of Preference comparisons were to be made considering only VFR conditions. Each of the fourteen monitoring gauges was to be considered in relation to each other and ranked in order of perceived importance from 1 (indicating the most important) to 14 (being the least important). In a like manner, the flight gauges were to be ranked from 1 to 9.

(c) Reliability

The third section concerned Reliability. As in the first section, the subjects were instructed to rate the fourteen monitoring gauges and the nine flight gauges. The rating was to reflect the subject's opinion as to the reliability of the information provided by each individual gauge. A rating of 1 indicated that the gauge could never be trusted, while a rating of 5 indicated that the gauge was highly reliable.

(d) Readability

The last section of the questionnaire involved Readability and was divided into six areas. The areas were: Errors in Reading, Discriminability, Operating Range, Scale, Scan Accuracy, and Night Lighting. The definition for each of these terms can be seen in Table 3. The subjects were again asked to consider and rate each instrument under six of the areas. The rankings ranged from 1 (very worst condition) to 5 (best condition), except for scan time where the ranks were reversed--5 (very worst condition) and 1 (best condition).

Table 3

Definitions of Readability Profile

Profile	Definition
Errors	Probability of making mistake in reading instrument.
Discriminability	Probability of confusing one instrument with another instrument.
Operating Range	Readability of instrument's operating range.
S[illegible]ling	Readability of scale used from distance pilot sits.
Scan Time	Ability to obtain information with least dwell time.
Night Lighting	Ability to read instrument under current night red light.

Data Analysis

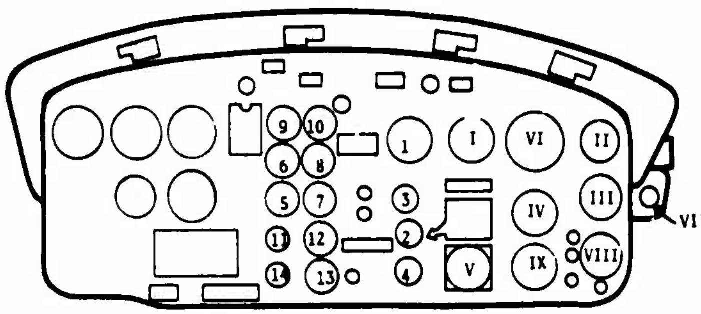
The first step in analyzing the data was to compute a mean rank for each display for each experience group across all sections of the questionnaire. This was accomplished by dividing the aggragate rank assigned by all respondees for that area by the number of respondees. These mean ranks were then ranked for each experience group over the various questionnaire sections and for the two display categories (monitoring gauges and flight instruments). Re-ranking the mean values actually yielded a comparative rank for each instrument relative to the rest of the instruments. For each section and display category a coefficient of concordance (W) was then computed to determine the relationship between the mean ranks for the three experience levels. The W ranges between 0 and 1 and is indicative of the degree of relationship that exists between the data. If the coefficient reached a level of significance (X^2) of .01 or greater, the ranks for the groups were submitted to a Friedman two-way analysis of variance to determine the probability that such a distribution of ranks across instruments would occur by chance. If W was not found to be significant, the ranks were not submitted to an analysis of variance and the distribution for each group is discussed.

RESULTS AND DISCUSSION

Frequency of Use

The coefficient of concordance (W) for the three instrument experience groups for each of the five flight segments can be seen in Table 4. All are significant at the .01 level or greater indicating a high level of agreement between the experience levels with regard to the frequency with which various instruments are thought to be used. Inasmuch as this agreement was high, a Friedman two-way analysis of variance was performed. With the exception of the pre-takeoff segment, agreement between experience groups was found to be significantly better than chance (X_r^2 > .01). Pre-takeoff did not exceed the .01 level of significance, which probably reflects the fact that the agreement between the various groups was not extremely high for this flight segment. Table 4 also shows the ranks for the combined computed ranks across experience levels. These combined values are presented inasmuch as the coefficient of concordance indicated that the groups acted in such a similar manner. When ranking instruments in terms of how often they are thought to be used, the conclusion for these analyses indicates that instrument qualification and experience level were not a primary effect. Such a finding could be expected since opinions regarding frequency of use would most likely be perpetuated as a function of training. It also can be seen that instruments can be ranked along the frequency of use continuum; i.e., instruments are ranked differently or judgments can be made as to the relative frequency with which instruments are used. This conclusion is supported by the analysis of variance and the existence of few ties.

Table 4 also reveals that instrument rankings across aircraft movement profiles (hovering, climb, cruise, descent) were quite similar for both monitoring gauges and flight displays. Further, it can be observed that the monitoring gauges, for the most part, can be logically grouped into four functional categories as a function of their rank, physical location and systems monitored. Figure 5 shows these categories and their location on the UH-1 instrument panel.



FREQUENCY OF USE—HOVER, CLIMB, CRUISE, DESCENT—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

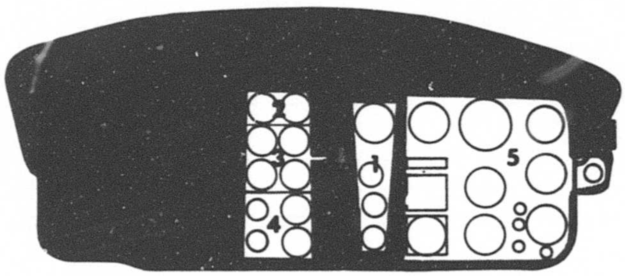
FIGURE 5

TABLE 4

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	7	3	10	3	3	3
Exhaust Temp.	3	4	8	4	4	4
OIL STATUS						
Trans. Oil Press.	4	6	3.5	5	5	6
Eng. Oil Press.	2	6	2	7.5	9	5
Trans. Oil Temp.	6	6	5	6	7.5	7.5
Eng. Oil Temp.	5	9	3.5	7.5	7.5	7.5
FUEL STATUS						
Fuel Pressure	10	10	9	9	10	10
Fuel Quantity	8	9	6	10	6	9
ELECTRICAL STATUS						
Main Generator	13	11	11.5	11.5	11	11
DC Voltmeter	11	12	11.5	13	12	12
AC Voltmeter	12	13	13	11.5	13	13
Standby Gen.	14	14	14	14	14	14
X_r^2	.01	.001	.05	.01	.001	.001
X^2 <	.01	.001	.01	.001	.01	.001
W^r <	.87	.93	.78	.91	.87	.93
FLIGHT DISPLAYS						
Airspeed Indicator	N A	N A	N A	1	1	1
Altimeter				2	2	2
VSI				3	3	3
RMI				4	4	5
Turn & Bank				5	6	4
Artificial Horizon				6	5	6
Magnetic Compass				7	7	7
Clock				8	8	8
VOR				9	9	9
X_r^2				.01	.01	.01
X^2 <				.01	.01	.01
W^r <				.95	.95	.95

Figure 6 depicts the panel location of the functional categories. During flight maneuvers, monitoring gauges concerned with engine performance were judged to be most frequently used, followed by those concerned with oil status, fuel status and electrical system status. Though oil status information was judged to be more frequently used than fuel status information, its panel position is below that of fuel information. Also, there is little question that electrical status information was judged to be the least frequently used of the monitoring gauges, a judgment which holds for all the segments explored. The flight displays are self explanatory, but when viewing their ranks it must be remembered that the aviators were asked to consider both IFR and VFR conditions.



DIVISIONS OF THE MONITORING GAUGES

1 ENGINE PERFORMANCE

Readout of constant change in performance of Engine

2 FUEL STATUS

Fuel Quantity & Fuel Pressure

3 OIL STATUS

Engine and Transmission oil temperatures and oil pressures

4 ELECTRICAL SYSTEMS STATUS

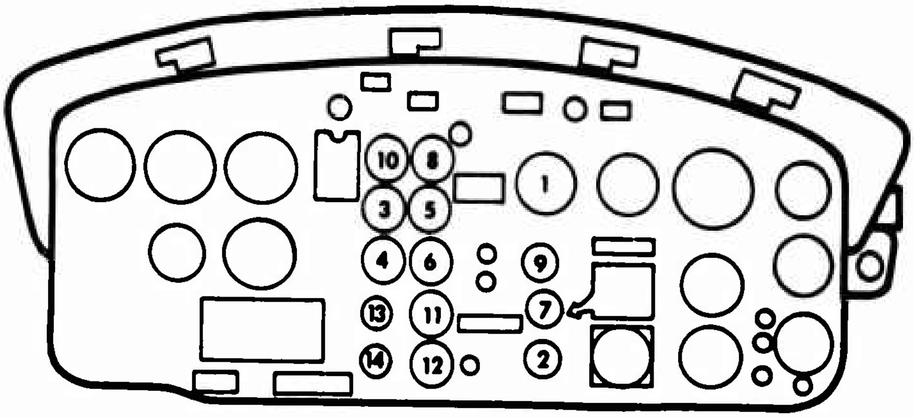
Monitor of DC and AC Electrical Systems

5 FLIGHT DISPLAYS

Information required to determine pilot inputs into Aircraft Flight Controls

FIGURE 6

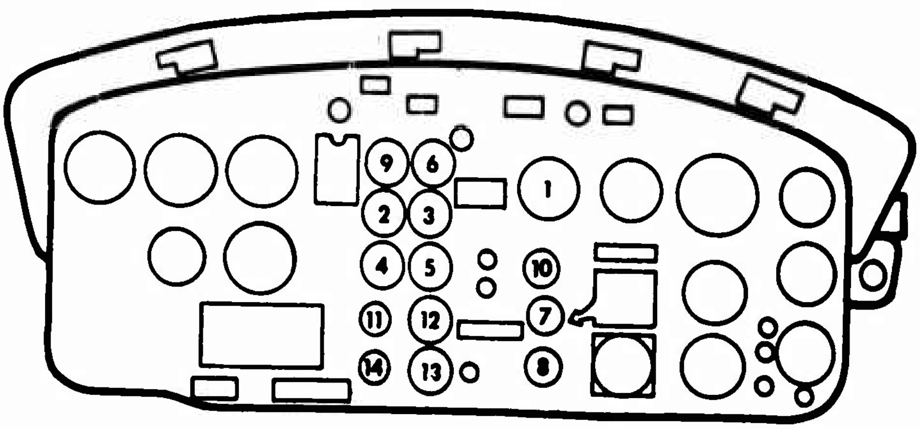
The instrument rankings during run-up and pre-takeoff segments differed from those involving aircraft movement and were also different one from another. These differences are probably precipitated by adherence to the Operator's Manual (-10) run-up and pre-takeoff start and checklists (See Figures 7 and 8).



RUN UP

Follows start list as outlined in Operator's Manual (-10) for UH-1

FIGURE 7



PRE TAKE OFF

Follows check list in -10 UH-1

FIGURE 8

Order of Preference

The next section of the questionnaire which was analyzed involved the Order of Preference or ranking the instruments in terms of importance. For this section, only VFR flight was to be considered. The statistical procedures utilized were the same as before. As can be seen in Table 5, W and X^2 indicate a fairly high degree of agreement between the various experience levels for both the monitoring gauges and flight displays. The X_r^2, however, indicates for the monitoring gauges that some interaction did exist between the experience level and instruments. That is to say, there was probably some difference of opinion as to what gauges were, in fact, most important. It can be seen that there was little overall agreement between how often a monitoring gauge was thought to be used as determined in the last section and the order of preference it was judged to have. However, one prominent exception is engine RPM which was judged to be most frequently used and most preferred. A second exception involves the electrical system status gauges. In the opinion of the aviators, these gauges were considered to be least in importance and usage. The previous categorization scheme found for the aircraft movement segments was not maintained for the preference data. However, it can be seen that one or two gauges were picked from each category. For example, engine RPM judged most important was from the engine performance category. The second and third most important, transmission and engine oil pressure, came from the oil status category and the fourth most important, fuel quantity, came from the fuel status category. This cycle was then to some degree repeated. With regard to the flight displays there were few shifts from the frequency of use rankings. However, it must be remembered that IFR flight was not considered. If this flight condition had been included, it is likely that there would have been a greater disparity between the preference and use ranks. For example, it would be expected that the artificial horizon would have been considered more important.

Reliability

The next portion of the questionnaire concerned opinion about the Reliability of instruments. A rank of 1 indicated that the instrument could never be trusted while a rating of 5 indicated that it was highly reliable. Table 5 indicates little overall agreement between the three experience levels for either the monitoring gauges or flight displays. Though overall agreement was low, there was less disagreement for monitoring gauges ($W = .69$, $X^2 = .02$) than for flight displays ($W = .34$, $X^2 = .50$). With regard to the monitoring gauges, all experience levels agreed that the engine RPM was the most reliable while fuel quantity was the least reliable. It is noteworthy that engine RPM was also judged most important and most often used. For the functional catergories of the monitoring gauges, the engine performance category, in general,

TABLE 5

IMPORTANCE - RELIABILITY

MONITORING GAUGES	IMPORTANCE	RELIABILITY		
	ALL AVIATORS	SQA	TQA	IQA
ENGINE PERFORMANCE				
Engine RPM	1	1	1.5	1
Gas Producer	5	3	1.5	2.5
Torque	8	4	3.5	6
Exhaust Temp.	6	2	6.5	2.5
OIL STATUS				
Trans. Oil Press.	2	9	5	6
Eng. Oil Press.	3	12	3.5	6
Trans. Oil Temp.	7	9	13	8.5
Eng. Oil Temp.	9	9	6.5	8.5
FUEL STATUS				
Fuel Pressure	10	13	11	4
Fuel Quantity	4	14	14	14
ELECTRICAL STATUS				
Main Generator	11	9	9	11.5
DC Voltmeter	12	5.5	9	11.5
AC Voltmeter	14	5.5	12	11.5
Standby Gen.	13	9	9	11.5
X_r^2	.05	-	-	-
X^2 <	.01	.02	.02	.02
W^r <	.89	.69	.69	.69
FLIGHT DISPLAYS				
Airspeed Indicator	1	3.5	4.5	5
Altimeter	2	7	6.5	7.5
VSI	4	5	4.5	4
RMI	3	1.5	8	6
Turn & Bank	6	3.5	2	1
Artificial Horizon	5	6	1	7.5
Magnetic Compass	7	9	3	9
Clock	9	8	9	2
VOR	8	1.5	6.5	3
X_r^2	.01	-	-	-
X^2 <	.01	.50	.50	.50
W^r <	.91	.34	.34	.34

was considered more reliable in comparison to the others. The largest disparity between the experience levels can be seen on the fuel pressure rank. The IQA group judged this instrument to be quite reliable where the SQA and TQA groups did not. The flight displays showed some agreement between the experience levels in that the altimeter became, on the average, the third least reliable of the nine displays. The SQA and TQA agreed that the magnetic compass was unreliable by comparison but the IQA did not agree with this assessment. The turn and bank indicator would appear to be considered more reliable as experience increases. It is also somewhat surprising that the IQA group's mean rank indicated by comparison that the artificial horizon was the third least reliable of the flight displays.

Readability

The last section of the questionnaire dealt with Readability which contained six sub-categories. These sub-categories involved opinions concerning the "probability of making a mistake in reading an instrument (Error); "the probability of confusing one instrument with another" (Discriminability); "the readability of the operating range of the instruments" (Operating Range); "the readability of the scale of the instrument from the viewer's position" (Scale); "the ability to obtain information with the least dwell time" (Scan Time); and "ability to read the instrument under current night red light" (Night Lighting).

Inasmuch as Error, Operating Range, and Scan Time would be expected to coincide, these sub-categories will be addressed first. Table 6 reveals that the three experience levels did not show overall agreement across the monitoring gauges with respect to these categories. Category coefficients of concordance ranged from .58 to .63. However, on particular instruments there was agreement within as well as across categories. For example, in the opinion of the instrument qualified aviators, the fuel quantity and gas producer gauges had a relatively difficult operating range to read, required more dwell time, and were likely to be associated with more errors. The tactical qualified aviators seemed to agree to some extent with the instrument qualified aviators with regard to the gas producer in terms of operating range and scan time, but not in terms of the likelihood of error. The students, on the other hand, apparently had the opinion that the operating range was reasonably good by comparison as was scan time; but, they would judge a fairly high error rate associated with the instrument. With regard to fuel quantity, the TQA's and SQA's were of the opinion that the operating range was quite readable, that scan accuracy was good and that there would be a low probability of making mistakes. The IQA's, on the other hand, did not agree. The SQA's and the TQA's were also of the opinion that the oil status instruments have poorly marked operating ranges which lead to increased scan time, but not necessarily error problems. The electrical status instruments were judged to have the

TABLE 6

ERROR - OPERATING RANGE - SCAN TIME

MONITORING GAUGES	ERROR			OPERATING RANGE			SCAN TIME		
	SQA	TQA	IQA	SQA	TQA	IQA	SQA	TQA	IQA
ENGINE PERFORMANCE									
Engine RPM	1	1	1	1	6	1	1	3	3
Gas Producer	12	6	14	5.5	8.5	9	4	7	11
Torque	3	3.5	2	4	4	2	2	2	1.5
Exhaust Temp.	12	13	8	5.5	14	8	8	14	10
OIL STATUS									
Trans. Oil Press.	7.5	14	4.5	11.5	11	4	13	5.5	6
Eng. Oil Press.	5	8	4.5	11.5	10	5.5	11	5.5	6
Trans. Oil Temp.	4	9.5	6.5	13.5	12	5.5	13	11	6
Eng. Oil Temp.	10	9.5	6.5	13.5	13	7	13	8	6
FUEL STATUS									
Fuel Pressure	7.5	2	3	3	1	3	5	1	1.5
Fuel Quantity	2	3.5	10.5	2	2	10	3	4	14
ELECTRICAL STATUS									
Main Generator	7.5	6	10.5	7.5	7	12.5	6.5	9.5	6
DC Voltmeter	14	12	9	9.5	8.5	12.5	9.5	13	12.5
AC Voltmeter	12	11	12	9.5	4	12.5	9.5	12	12.5
Standby Gen.	7.5	6	13	7.5	4	12.5	6.5	9.5	9
X_r^2	-	-	-	-	-	-	-	-	-
$X^2 <$	-	-	-	-	-	-	-	-	-
$W' <$	.63	.63	.63	.61	.61	.61	.58	.58	.58
FLIGHT DISPLAYS	ALL AVIATORS						ALL AVIATORS		
Airspeed Indicator		1						1	
Altimeter		6						8	
VSI		2						4	
RMI		7						2	
Turn & Bank		3						6.5	
Artificial Horizon		5			NA			3	
Magnetic Compass		9						9	
Clock		4						6.5	
VOR		8						5	
X_r^2		.01						.01	
$X^2 <$		.001						.01	
$W' <$		.92						.86	

poorest overall operating ranges by the IQA's, which appeared to translate to their opinions concerning scan time and errors. The SQA's and TQA's also mirrored this opinion; but, for the most part, to a lesser degree. The TQA's were of the opinion that the EGT gauge had operating range problems, required long dwell times and could be misread. This opinion was supported to some extent by the SQA's and IQA's. With the exception of the TQA's, the RPM gauge was judged to have a reasonable operating range, required comparatively little time to scan, and was associated with a minimum of error. It might be remembered that the gauge was also judged to be most often used, most preferred, and most reliable. The IQA's and TQA's agreed that fuel pressure was also pretty good in terms of the three parameters under discussion.

The three groups of aviators agreed to a large extent on the scan times required for the flight displays and their potential for error. The coefficients of concordance of .86 and .92 ($p < .01$) and the ANOVA's indicate that the instruments could be ranked. As can be seen in Table 6, the airspeed indicator was judged to require the least amount of time to read and the magnetic compass the next. The A/S indicator was also judged to be the most preferred and least likely to precipitate errors. The altimeter on the other hand was judged to take the second longest time to read while being the second most frequently used instrument and ranked 6 in the probability of being associated with reading error.

The next sub-category of readability to be addressed concerned Discriminability or the probability of confusing one instrument with another. Table 7 indicates that the three experience levels were in good agreement on this category ($W = .96$, $X^2 > .01$), and the instruments did dictate the ranks assigned ($X^2_T > .01$). Perhaps the most noteworthy area involves the engine/transmission oil pressure and temperature cluster. In the opinion of the aviators, if confusion were to occur it would likely stem from these.

The next sub-category dealt with Scaling or the readability of the scales of the instruments. Again, as can be seen in Table 7, the monitoring gauges yielded very little agreement. The number of tied ranks would indicate that many instruments were judged about equal, which would be expected in that most are designed to the same legibility specifications. It is interesting that the IQA's judged the electrical status display best from a scaling point of view, a result which is probably a function of fewer numbers and "tic" marks. The flight display ranks were in fair agreement across groups ($W = .71$), but not enough to attain statistical significance. The number of tied ranks would indicate that opinions about the scaling on flight instruments were similar.

TABLE 7

DISCRIMINABILITY - SCALING - NIGHT LIGHTING

	DISCRIMINABILITY	SCALING			NIGHT LIGHTING	
MONITORING GAUGES	ALL AVIATORS	SQA	TQA	IQA	TQA	IQA
ENGINE PERFORMANCE						
Engine RPM	1	8.5	5	8	1	1
Gas Producer	5	13	7	10.5	12	10
Torque	3	10	5	12.5	8	8
Exhaust Temp.	3	14	13	12.5	14	12
OIL STATUS						
Trans. Oil Press.	13	5	8.5	8	10	3.5
Eng. Oil Press.	14	5	8.5	10.5	8	3.5
Trans. Oil Temp.	11	1.5	12	5.5	11	6.5
Eng. Oil Temp.	12	1.5	14	5.5	13	3.5
FUEL STATUS						
Fuel Pressure	9.5	5	1	8	2	3.5
Fuel Quantity	3	5	2.5	14	2	6.5
ELECTRICAL STATUS						
Main Generator	6	5	5	2.5	5.5	10
DC Voltmeter	7	12	10.5	2.5	8	13.5
AC Voltmeter	8	11	10.5	2.5	8	13.5
Standby Gen.	9.5	8.5	2.5	2.5	5.5	10
X_r^2	.01	-	-	-	-	-
X^2 <	.01	-	-	-	-	-
W^r <	.96	.33	.33	.33	.62	.62
FLIGHT DISPLAYS						
Airspeed Indicator	NA	2	1	2	2	6
Altimeter		2	7.5	6	5	5
VSI		6	5	2	3	4
RMI		6	3	9	4	1
Turn & Bank		6	9	7	6	7
Artificial Horizon		4	7.5	2	1	2
Magnetic Compass		9	6	4.5	9	9
Clock		2	2	3	8	8
VOR		8	4	8	7	3
X_r^2		-	-	-	-	-
X^2 <		-	-	-	-	-
W^r <		.71	.71	.71	.81	.81

The last sub-category addressed the ability to read the instruments under current Night Red Lighting. No data was gathered from the SQA's for this category because of their minimal experience. One can see in Table 7 that the monitoring gauge data by the IQA's and TQA's reflects little overall agreement. Specifically, however, there is agreement that engine RPM is the easier of the instruments to read while the harder instruments are the EGT and gas producer. For the flight instruments there was better agreement (W = .81) but not enough to obtain statistical significance. The ranks do, however, indicate that the magnetic compass, followed closely by the clock and turn and bank indicator, were more difficult to read than the other instruments.

CONCLUSIONS

To summarize the data collected, the following graphs illustrate comparisons between the mean response of the 54 aviators across the 23 instruments and allow comparisons of the same instruments in the different sections; i.e., frequency of use, reliability, etc. All sections were to be considered under both IFR and VFR conditions except for the order of preference section which was under VFR conditions only. If the three aviator groups agreed significantly, only one graph will reflect the total mean response. If there was lack of agreement, the aviator groups will be compared to each other. The following table depicts abbreviations for the 23 gauges used in the graphs.

TABLE 8

Instrument Abbreviations

RPM	- Revolutions Per Minute Gauge	AC	- Alternating Current Voltmeter
GP	- Gas Producer	SG	- Standby Generator
TQ	- Torque	AS	- Airspeed Indicator
EGT	- Exhaust Gas Temperature	ALT	- Altimeter
TOP	- Transmission Oil Temperature	VSI	- Vertical Speed Indicator
EOP	- Engine Oil Pressure	RMI	- Radio Magnetic Indicator
TOT	- Transmission Oil Temperature	T&B	- Turn and Bank
EOT	- Engine Oil Temperature	AH	- Artificial Horizon
FQ	- Fuel Quantity	MC	- Magnetic Compass
FP	- Fuel Pressure	CL	- Clock
MG	- Main Generator	VOR	- OBS Indicator
DC	- Direct Current Voltmeter		

Figure 9 reflects the mean response of how often or how rarely the three aviator groups used the flight gauges. It can be seen that only the airspeed, altimeter and vertical speed indicators were judged to be used more than just occasionally, with the artificial horizon being only rarely used. With the exception of the turn and bank indicator, there is a decrease of usage across all nine instruments regardless of the type of maneuver.

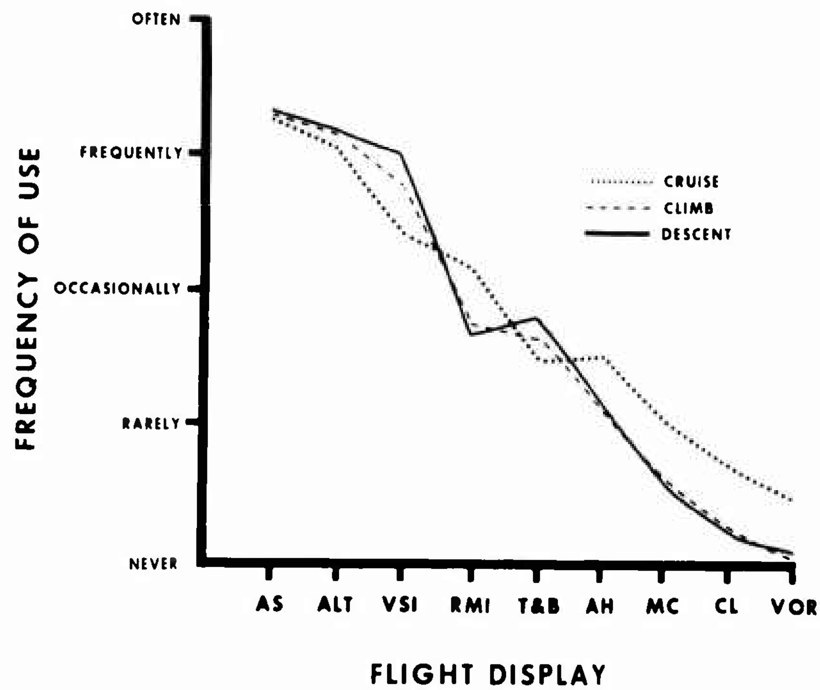
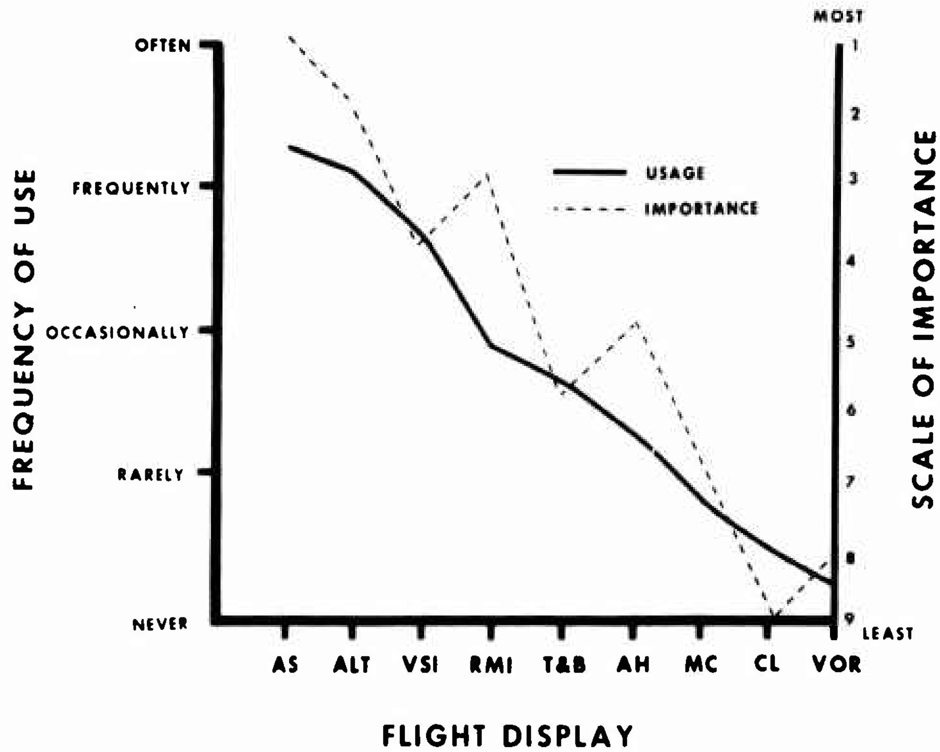


FIGURE 9. USAGE OF THE FLIGHT DISPLAY

The three flight maneuvers from Figure 9 were combined and can be seen in Figure 10 along with the importance the 54 aviators placed on each instrument. The scale for the frequency of use appears to the left of the graph, with the scale for importance to the right. It would appear from this figure that aviators are of the opinion that with knowledge of airspeed, altitude, and direction, they need only scan the rest of the gauges occasionally to successfully fly. Other minor deviations between usage and importance appeared between the artificial horizon and the turn and bank indicator and between the VOR and clock. In general, however, the instruments were ranked similarly for frequency of use and importance.

As can be seen in Figure 11, there was no agreement between the three experience levels with respect to their opinion about the reliability of the flight gauges. Generally, however, it reveals that disagreement is related to experience with the instrument rated aviators rating the flight displays most reliable. The IQA's and the TQA's rated the turn



FIGUSE 10. COMPARISON OF PILOT OPINION OF IMPORTANCE VS USAGE OF FLIGHT DISPLAY

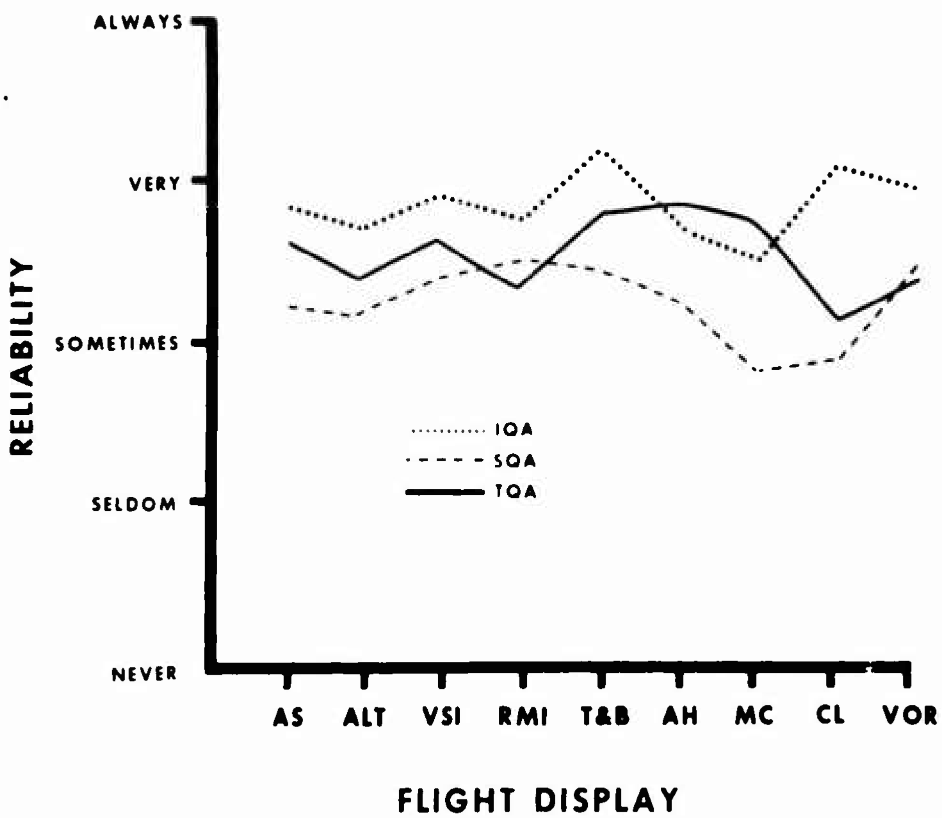


FIGURE 11. PILOT OPINION OF THE RELIABILITY OF FLIGHT DISPLAY

and bank as most reliable while the IQA's and SQA's rated the magnetic compass the least reliable. It might be noted that all flight instruments were rated above average.

Figure 12 illustrates the comparison of time and reading error for all the flight displays. In general, it would appear that problems with reading errors were considered to be minimal. The magnetic compass, however, by comparison was judged to be the worst for both error in reading and time to scan.

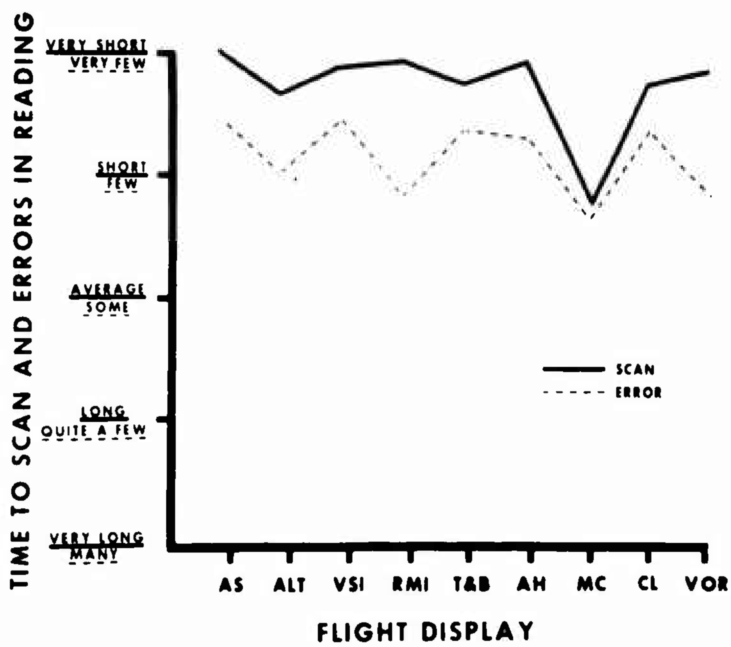


FIGURE 12. COMPARISON OF TIME TO SCAN AND ERRORS IN READING FOR FLIGHT DISPLAY

The opinions of the three aviator groups concerning the scaling of the the flight gauges reflected almost no agreement as can be seen in Figure 13. Although the scaling of the instruments was rated to be generally satisfactory by all three groups, the TQA's felt that the airspeed indicator needed better color coding and the turn and bank indicator needed changes in the division of the scaling.

The final section concerned with flight display was the TQA's and IQA's opinion of the cockpit lighting. Figure 14 shows the magnetic compass again was ranked worst followed by the turn and bank indicator. Both groups agreed that the artificial horizon display was the easiest from which to gain information under current night lighting. Flight instruments, with the exception of the magnetic compass, were considered by the aviators to be above average in readability with current cockpit night lighting.

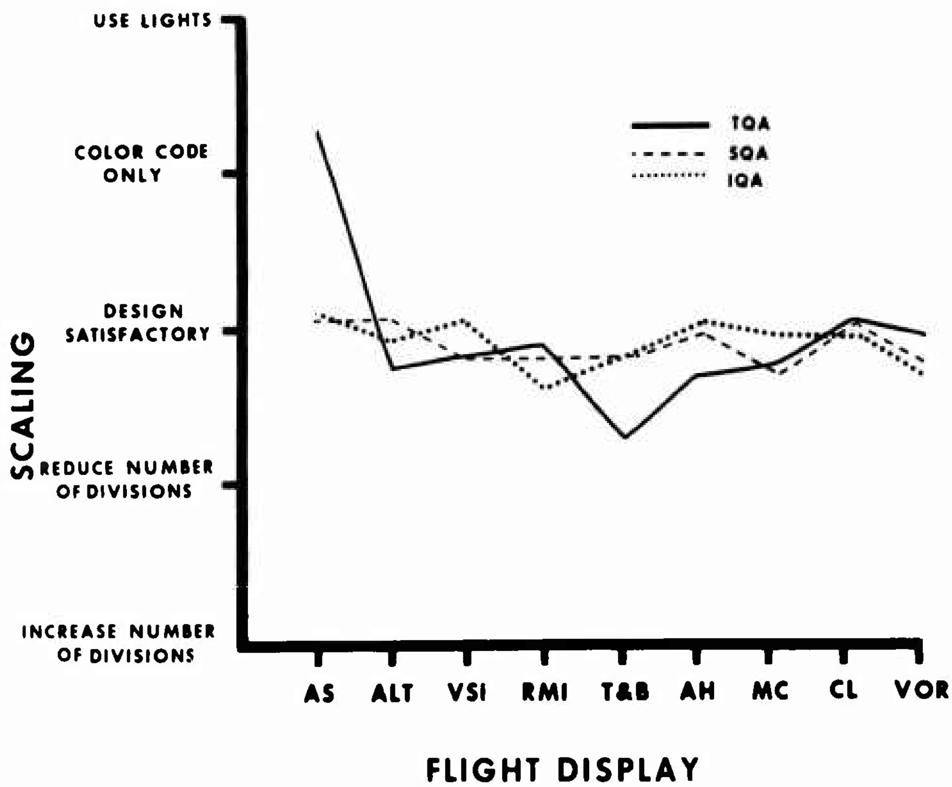


FIGURE 13. OPINION OF SCALING USED IN THE FLIGHT DISPLAY

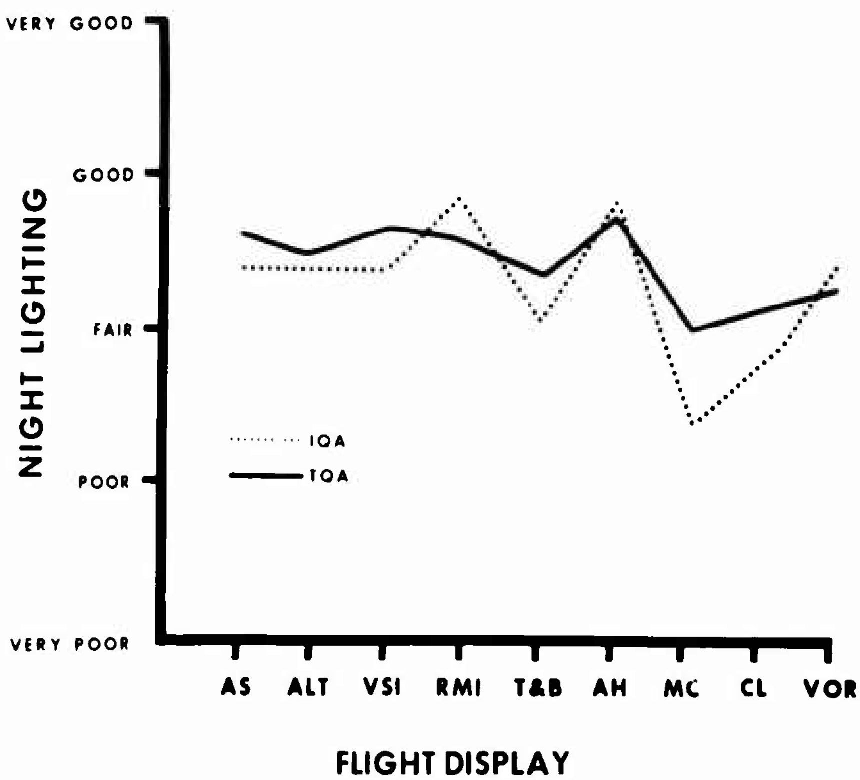


FIGURE 14 OPINION OF READABILITY OF FLIGHT DISPLAY UNDER CURRENT NIGHT LIGHTING

In the section of the questionnaire concerning the frequency of use of the monitoring gauges, there is agreement among the aviator groups. When comparing the fourteen instruments it becomes apparent that they can be separated into four instrument groups: engine status, oil status, fuel status, and electrical status. Figure 15 illustrates the division of these groups as reflected through their frequency of use during flight maneuvers. Although system controlled and not manipulated by the aviator during normal flight maneuvers, the RPM is considered to be the most frequently used instrument, while the electrical monitoring gauges are judged to be rarely used.

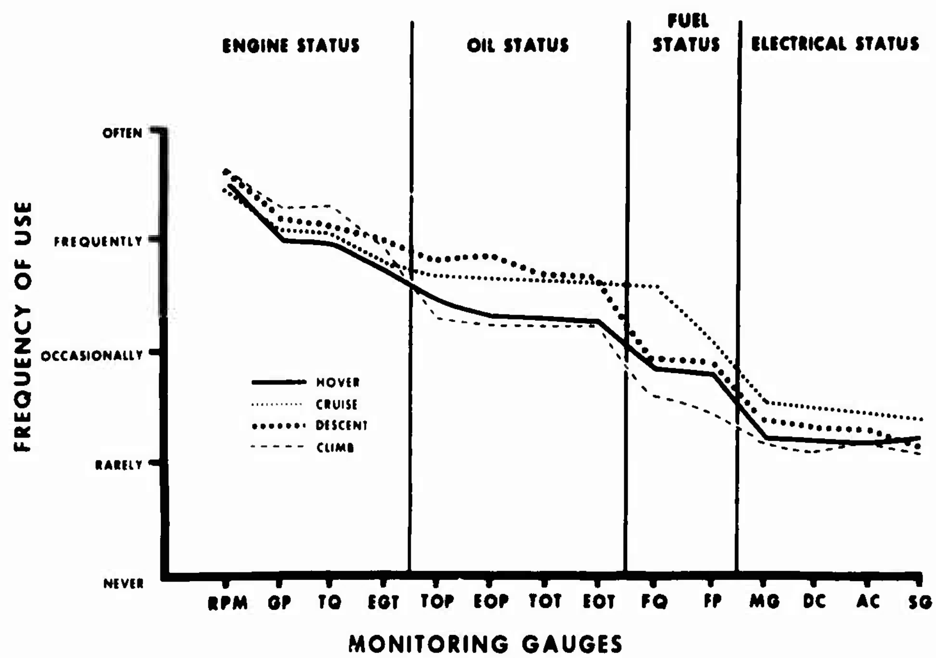


FIGURE 15. COMPARISON OF THE FREQUENCY OF USE OF THE MONITORING GAUGES DURING FLIGHT MANEUVERS

The frequency of use data across the four flight maneuvers are combined and presented in Figure 16 along with the aviators' opinions concerning frequency of use during pre-takeoff and run up. The usage of instruments during pre-takeoff and run up are similar in form but generally have a higher frequency of use than that found for the flight maneuvers. As mentioned previously, pre-takeoff and run up are controlled by checklist which may explain these results. Again, across all three conditions, the electrical gauges are used occasionally-to-rarely while the RPM is considered most used.

Comparison data between frequency of use, relative importance and discriminability for the monitoring gauges can be seen in Figure 17. The scale for importance is located on the right side of the graph while the scales for the other two parameters are located on the left.

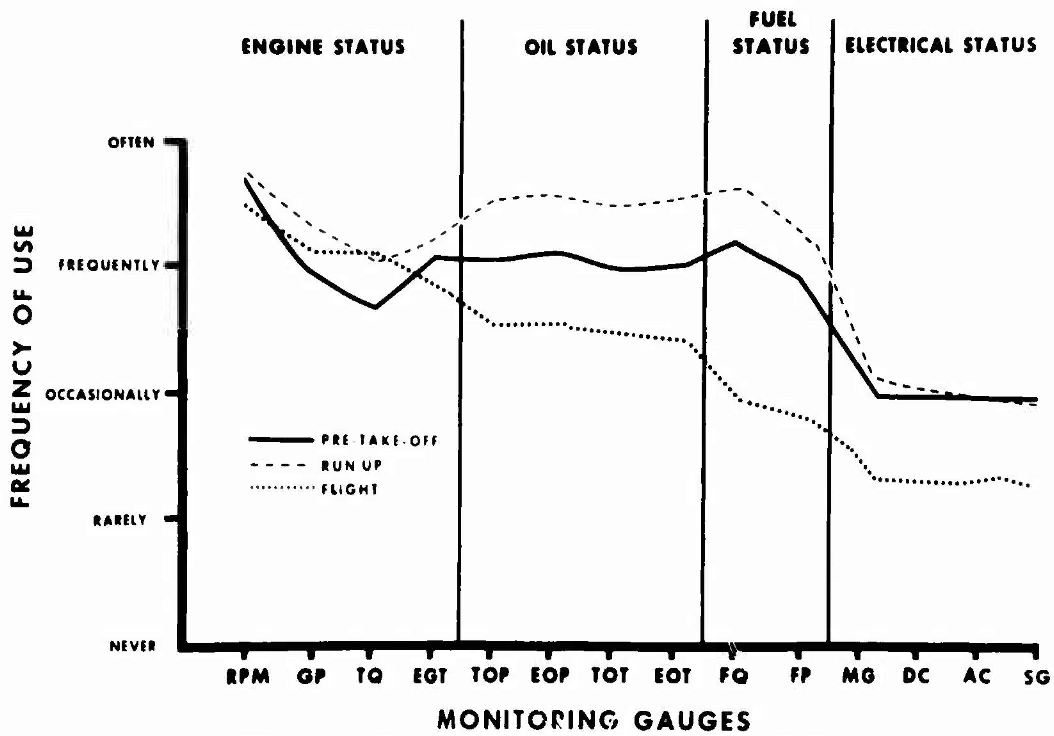


FIGURE 16. COMPARISON OF THE FREQUENCY OF USE OF THE MONITORING GAUGES DURING PRE-TAKE OFF, RUN UP, AND FLIGHT

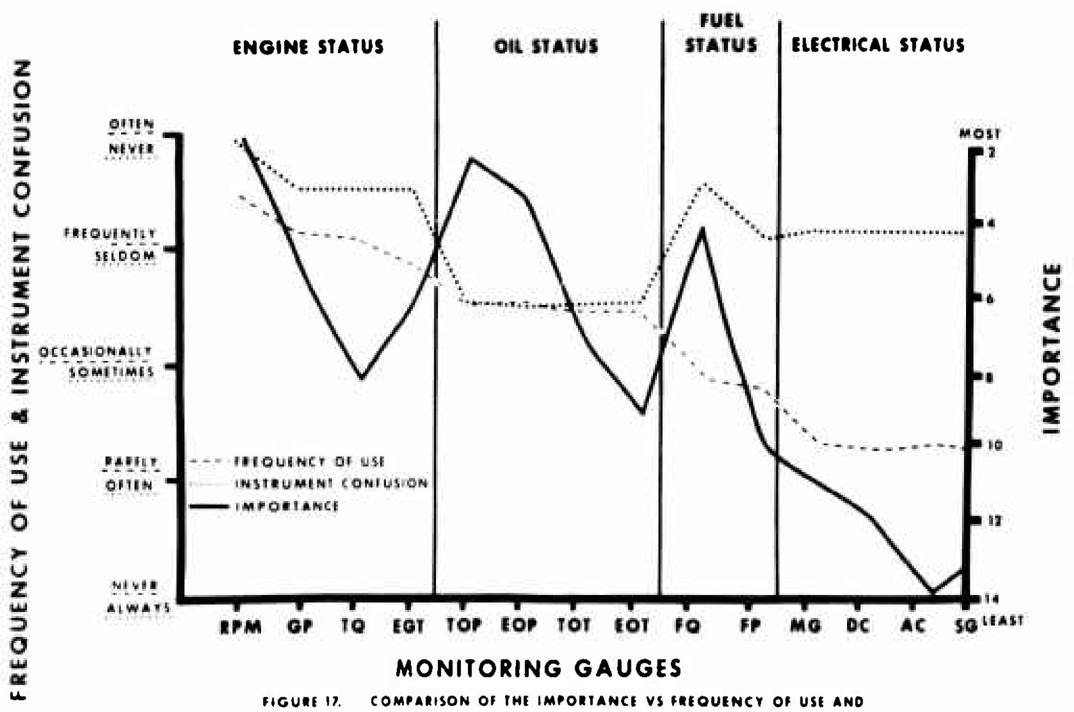


FIGURE 17. COMPARISON OF THE IMPORTANCE VS FREQUENCY OF USE AND CONFUSION IN READING OF THE MONITORING GAUGES

As noted previously, the RPM gauge ranks highest across all three scales while the electrical gauges are judged to be least important and rarely used. In the fuel status group, although the fuel quantity gauge is thought to be less than occasionally used, the aviators judged it to be fourth in importance and rarely confused it with other instruments. The frequency of use for the oil pressure gauges, both transmission and engine, rank the same as the temperature gauges and all are rated most difficult to discriminate. However, these pressure gauges are considered highly important. One of the major indicators of available power is the torque gauge; and although frequently utilized, it is ranked below average in importance.

Figure 18 reflects the aviators' opinions about instrument reliability. The IQA's ranked all the instruments more reliable than did the SQA's and the TQA's. All experience levels ranked the monitoring gauges at the normally reliable level except for fuel quantity which they felt was the least reliable.

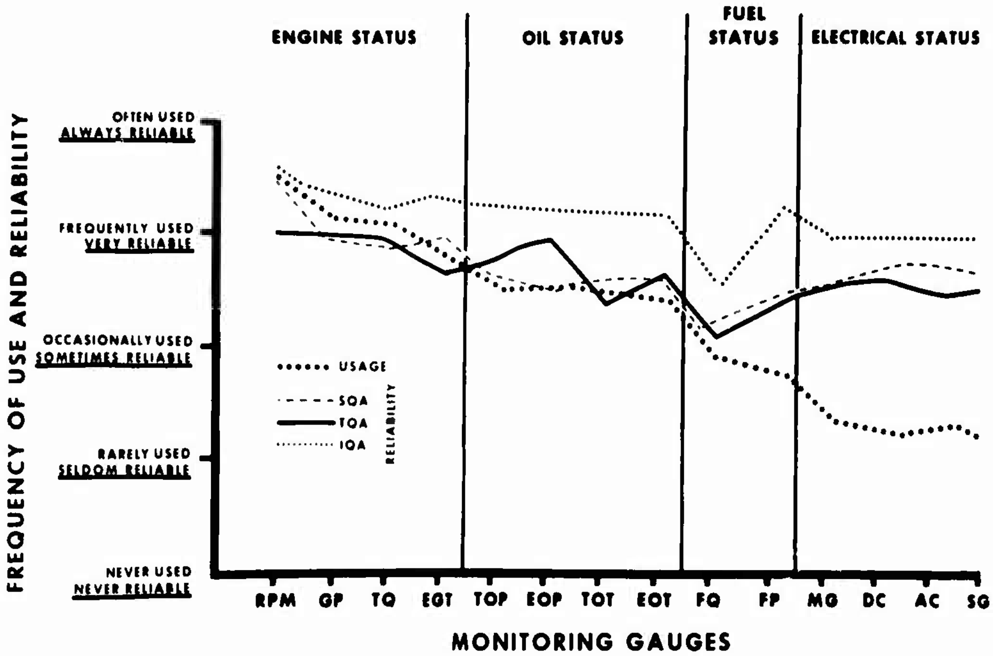


FIGURE 18. PILOT OPINION OF THE FREQUENCY OF USE & RELIABILITY OF THE MONITORING GAUGES

The sections on reading error, scan time, operating range, scaling, and night lighting of the monitoring gauges shows no agreement across experience levels. Figure 19 compares the opinions of the separate experience levels on the probability of errors in information transfer from the monitoring gauges. The TQA's and the SQA's rated the transmission oil pressure the worst instrument for reading errors. This is the same instrument which was ranked most important but most difficult to discriminate from other instruments. All aviators felt that they were more likely to make errors reading the gas producer than the torque gauge.

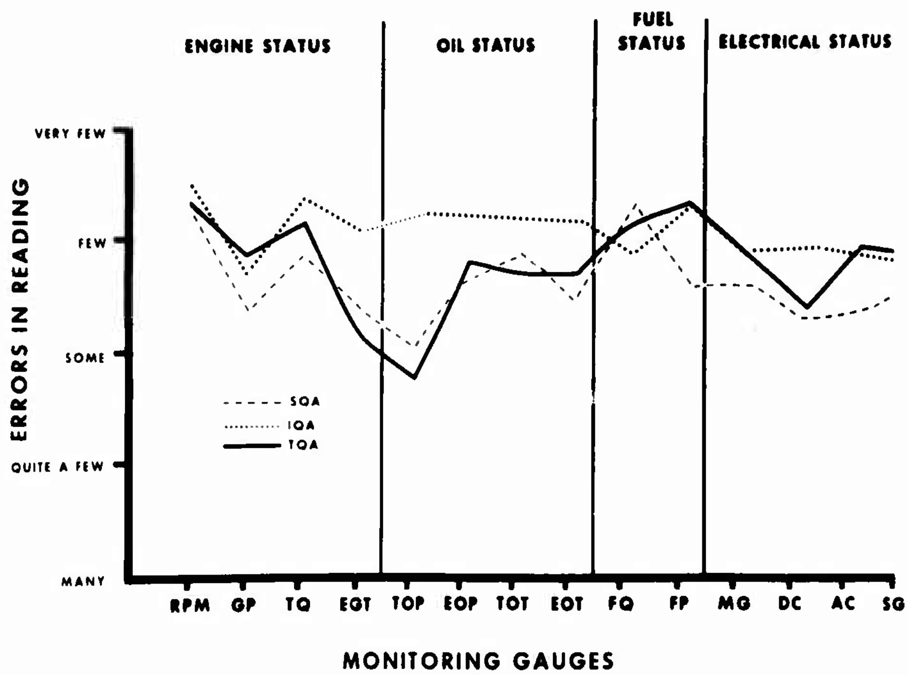


FIGURE 19. ERRORS IN READING THE MONITORING GAUGES

The scan time data, which can be seen in Figure 20, shows little agreement across instruments and experience levels. All did agree, however, that it took less scan time to read the torque gauge than the gas producer gauge even though the gas producer uses an integrated two pointer system. The oil status group appears to be a function of experience with less experienced aviators having the most trouble with scan time on these gauges.

As seen in Figure 21, operating range reflects a similar outcome to that of scan time in that the oil status category ranks appear to be a function of experience with the TQA's and SQA's having poor opinions of these gauges. However, all experience levels felt that the operating range of the torque gauge was better than that of the gas producer gauge.

Figure 22 shows that for scaling both SQA's and IQA's want more divisions on EGT, TOT, EOT and color coding for the fuel pressure gauge.

Ranking of night lighting, as shown in Figure 23, appears to be related to experience. Both groups, however, ranked all the gauges as being fairly readable under current cockpit lighting with EGT being ranked worst of the monitoring gauges.

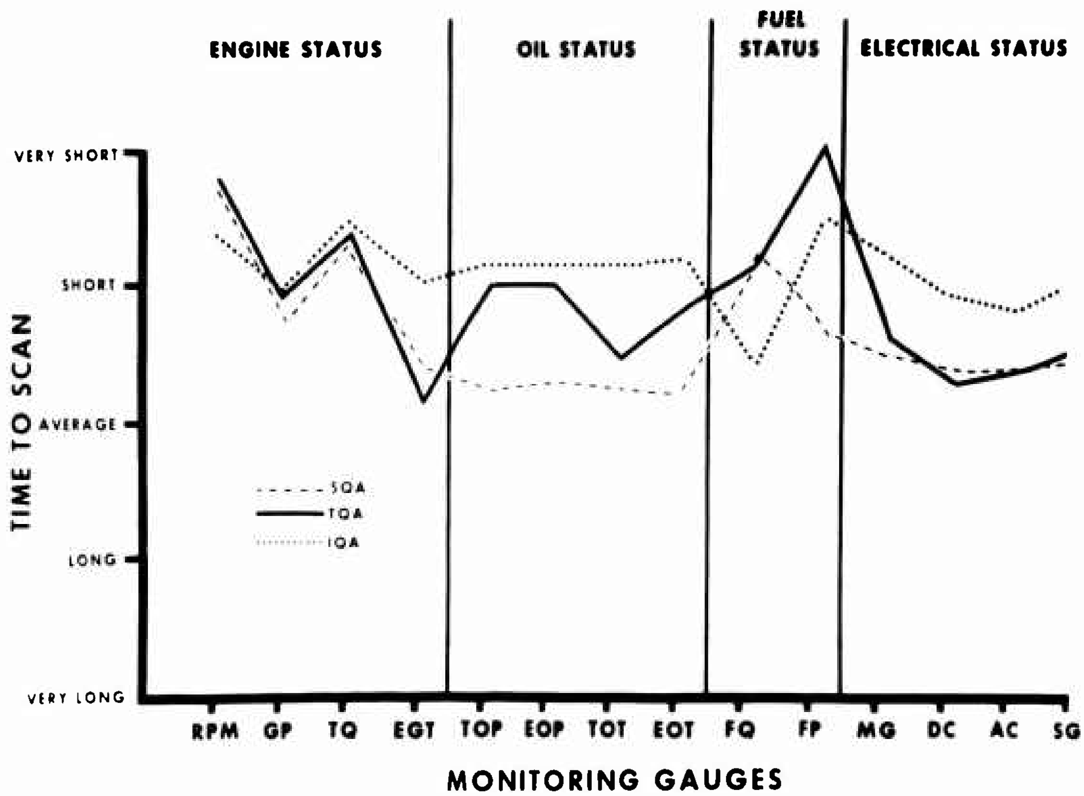


FIGURE 20. TIME TO SCAN THE MONITORING GAUGES

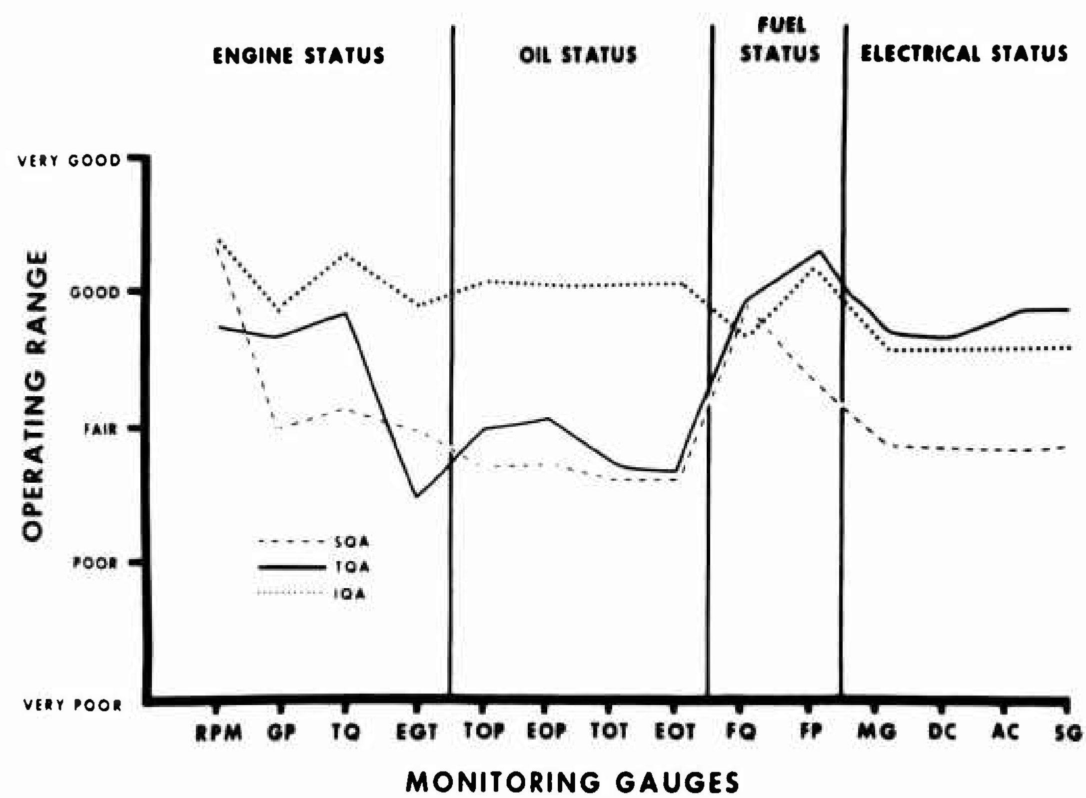


FIGURE 21. OPINION OF OPERATING RANGES OF MONITORING GAUGES

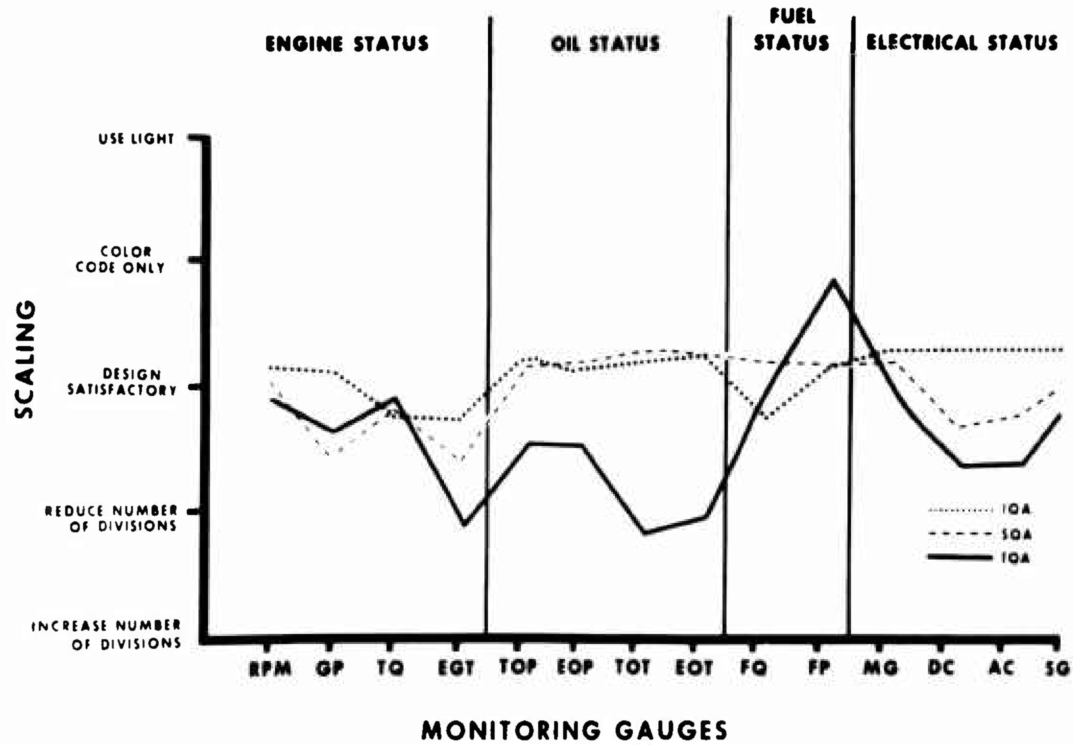


FIGURE 22. OPINION OF SCALING OF MONITORING GAUGES

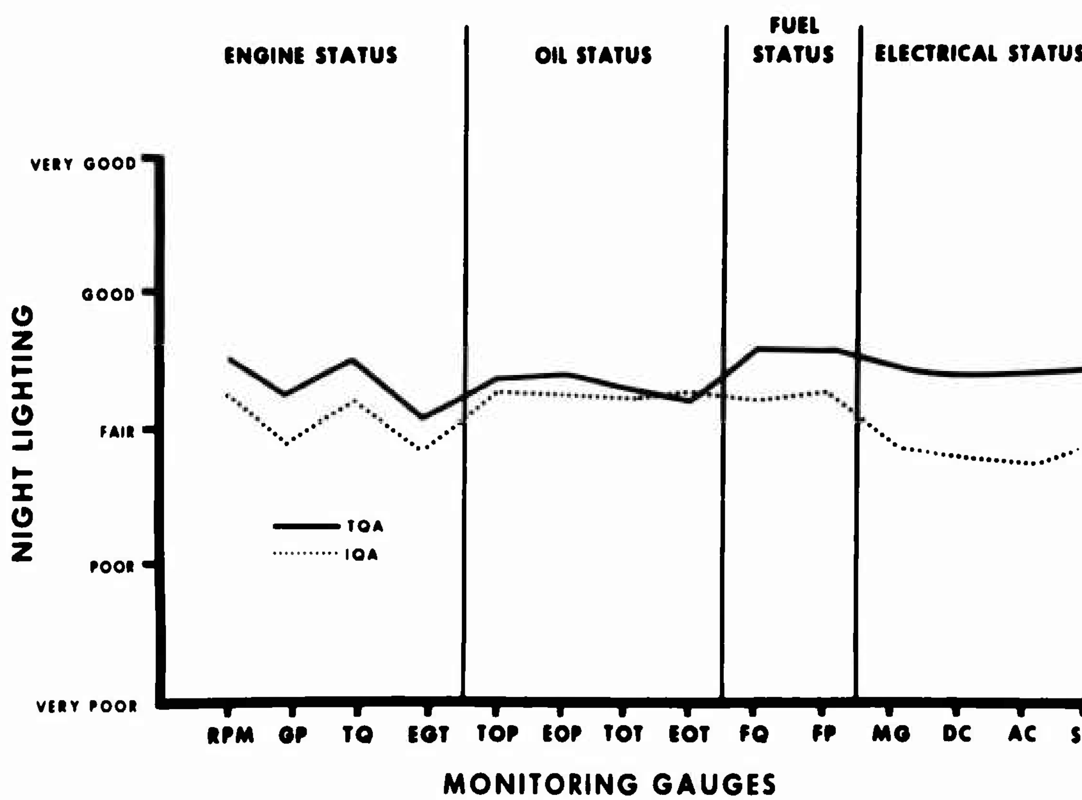


FIGURE 23 READABILITY OF MONITORING GAUGES UNDER CURRENT NIGHT LIGHTING

In summary, it appears that aviators, regardless of experience level, can agree on which instruments are most important and the relative frequency with which they are used. However, areas of reliability and readability show a large variance of opinion with all groups ranking the instruments in the average or satisfactory range for lack of any definite opinion.

Based on these data it is surprising that the RPM gauge, which in the UH-1 helicopter is system controlled and is relatively stable throughout all maneuvers, is rated as most important, most used, most reliable and easiest to read. Although the gas producer gauge is judged to be more frequently used, more important, and more reliable than the torque meter, the torque meter is judged to have a better operating range, requires less time to read, and produces fewer errors. The EGT gauge perhaps should be considered for better operating range and better scaling. Ranks for the oil status and fuel quantity gauges reflect the need for a better operating range and greater reliability. A digital printout system might solve the operating range problem. Because the electrical system is judged to be neither used nor important, perhaps the system should be considered for caution lights which would increase usable panel space. The aviators agreed that among flight monitoring gauges, the airspeed, altitude and vertical speed indicators were the most used and most important; yet the artificial horizon, comprising the largest area of the panel and best viewing angle, is rated fifth most important during VFR conditions and sixth most used during both VFR and IFR conditions.

Changes are possibly warranted for the magnetic compass which was judged unreliable, producing the most errors in reading, associated with worst scan time and worst lighting. The Hobbs' three-pointer altimeter reflected poor scan time and error in reading, a situation which could possibly be remedied with a counter-drum-pointer altimeter. The navigation instruments (the OBS, magnetic compass and the radio magnetic compass) collectively are judged to have the most error in information transfer. This would indicate that better integrated horizontal situation indicators may need to be considered. The turn and bank indicator appeared to have the worst scale of the flight display.

One of the main purposes of this questionnaire was to expand the present data concerning the visual cue requirements for helicopter flight. This subjective data reflects the opinions of the aviator, but should be tempered by the fact that with regard to visual performance there is often disparity between subjective data and objective values. Studies are now being conducted that will yield objective data which will not only expand the data base but also provide information about the correlation between certain aspects of subjective opinions concerning instruments and what actually occurs.

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3. Ricketson, Darwin S., Johnson, S. A., Branham, L. B., and Dean, R. K. Incidence, cost and factor analysis of pilot-error accidents in US Army aviation. AGARD-CP-132. Paper presented at the Aerospace Medical Panel Specialists Meeting, Soesterberg, Netherlands, September 1973.

A P P E N D I X   A

Examples from 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.														