EFFICIENT EYE-SCANNING FOR REDUCING PILOT WORKLOAD -SINGLE PILOT IFR AND VFR FLIGHT TESTS-

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Abstract

Tests were conducted by a flight simulator and by an actual flight to investigate how a pilot flies an airplane by effectively utilizing the instrument information obtained by eye scanning. The differences between IFR and VFR flights are also discussed. First, flight simulator tests were done by several examinees who have had different flight experiences. Experienced pilots fly the airplane with an attitude instrument flying technique that mainly utilizes the information from the primary instruments. Second, actual IFR test results indicated the importance of eye scanning over the basic T-configured instruments. Similar results cannot be obtained between the flight simulator and the actual flight, unless the examinee flies the flight simulator with a consciousness that he is flying an actual airplane. Third, actual VFR test results indicated that the pilot can fly the airplane safely as long as he scans the proper instruments that are needed in a specific flight situation.

Nomenclature (Abbreviations)

AI	attitude indicator
ALT	altitude indicator
AS	air speed indicator
ASL	above sea level
HDG	heading angle indicator
IFR	instrument flight rule
MSL	mean sea level
RPM	engine tachometer
TCD	turn coordinator
VFR	visual flight rule
VSI	vertical speed indicator

1 Introduction

Operations under single pilot instrument flight rules (SPIFR) for general aviation aircraft is known to be one of the most demanding pilot tasks. The pilot under SPIFR without an autopilot has to fly the airplane manually by selecting necessary information from numerous flight avionics. He also has to handle all communications including numerous frequency changes, navigate using many necessary charts, and comply with ATC procedures. Pilots who have a lot of flight experience fly airplanes under SPIFR, safely and efficiently. They have gained the capability to maintain the safety of the flight and reduce their workload due to their long-time flight experiences. Therefore, it is believed that the efficient way of flying can be found by investigating the flight characteristics of experienced pilots through workload evaluation studies. In Reference 1, pilot workload measurements using a PC-based flight simulator have been done to investigate what kind of flight skills and experiences have reduced the pilot workload.

In this paper, further study has been conducted to investigate how the pilot flies an airplane by effectively utilizing the instrument information obtained by his eye scanning. Tests were conducted both by a flight simulator and by an actual flight. Differences between IFR and VFR flights are also discussed.

2 Flight Simulator Tests

Flight simulator tests were done by several examinees who have different flight experiences.

Examinees performed the straight and level IFR flight by using the PC-based flight simulator.

2.1 Experimental Apparatus and Methods

The experimental apparatus (Figure 1a) mainly consists of a flight simulator and some data recorders. A PC-based flight simulator for the instrument flight training was used (CirrusII flight console made by Precision Flight Controls Inc. and software Elite Ver. 5.1). This software simulates the instrument flight of a single engine propeller driven aircraft, Cessna 172. The instruments for VFR and IFR are shown on the PC screen. The flight console has a control yoke, throttle lever, rudder pedal, elevator trim and control panel for its navigation equipment. Another PC was used to record the pilot's operation of the control surfaces and other flight equipment. This PC is directly connected to the flight console to monitor his operations. An eye-mark recorder (NAC, EMR-7) was used to record the examinee's eye movement. An example of the picture recorded by the eye-mark recorder is shown in Fig.1b. The instruments shown on the PC screen was video-recorded by another CCD camera to record the altitude, heading and attitude of the aircraft.

By using these apparatus, time histories of the flight parameters were obtained. The eye-mark recorder was used to record the instruments that the examinee was looking at. The duration of time that he spent looking at one particular instrument was recorded in 30Hz. The instruments recorded by the eye-mark recorder were the attitude indicator (AI), altimeter (ALT), heading indicator (HDG), airspeed indicator (AS), turn coordinator (TCD), vertical speed indicator (VSI), VOR and engine tachometer (RPM). The bank angle, pitch angle, altitude, heading, airspeed, turn rate and vertical speed were obtained from the video-recorded data by the CCD camera in 3Hz.

Six pilots who have different flight experiences attended the tests. The examinee's data are shown in Table 1. The examinees are called A, B, C, D, E and F, according to the amount of flight time each examinee has obtained, A being the longest. Three of the pilots have commercial licenses, two have private pilot licenses and one does not have either.

The flight scenario used for the experiments was a straight and level IFR flight (maintain heading 160°, altitude 3000feet and airspeed 110kts). Wind and turbulence were not added into the scenario.

2.2 Results and Discussion

Figure 2 shows the time history of the measured parameters of examinee A. There are some bold-lines in the upper and lower parts of this figure. These denote that the examinee is looking at a specific instrument at this time. The AI indicates both the bank angle and the pitch angle. In this figure, it was assumed that the examinee is looking at both the pitch angle and the bank angle at the same time, when he is scanning the AI. The origin of the time axis is located at the start of the test.

Figure 2 indicates that examinee A is adjusting the altitude until about 90sec. He controls the elevator frequently in spite of the level flight. After 95sec, he can maintain the altitude and heading quite well.

Figure 3a indicates the scanning ratio of each instrument during the test by examinee A. This figure indicates the normalized total time in which the examinee looked at each instrument during the flight test. The average value of all examinees is also shown in a dotted line for each instrument. In this figure the time ratios when the examinee scans both the pitch angle and the bank index in the AI are plotted separately. This figure shows that examinee A is mainly looking at the pitch angle in the AI. By scanning this instrument, he obtained information about the pitch angle.

Figures 3b-3f show similar test results by examinees B, C, D, E and F. Results of examinees B and C who are commercial pilots (Figs. 3b and 3c) indicate that high scanning ratios are plotted for the pitch angle in the AI as was in Fig.3a.

Results by the private pilot D (Fig.3d) show that his scanning ratio of the pitch angle is high. He also scans bank index in the AI frequently. However, according to the time histories of flight parameters by examinee D shown in Fig.4, he is adjusting the aileron frequently and he cannot maintain constant bank angle. This may be due to examinee D's limited flight experience.

Results by examinee E, who does not hold the instrument flying rating (Fig.3e), shows he seldom scans the AI and scans the TCD excessively which is not the appropriate way to fly under IFR.

Results by non-pilot F in Fig.3f shows that the scanning ratio distributions are totally different from those by examinees A-D.

These results suggest that scanning the pitch/bank angles and maintaining these angles are the important factors in performing a correct straight and level flight under IFR. This piloting technique may be able to reduce the pilot workload.

One of the basic techniques in flying an airplane under IFR is attitude instrument flying [2]. This technique regards the airplane attitude as a function of the pitch, bank and power control. These factors are termed primary factors and the others are termed supported factors. This technique is also called a primary/support concept. From Fig.3's results, it can be said that examinees A-D have been flying under this concept.

There are three common scanning errors when the pilot scans the instruments. They are fixation (stop scanning and stare at single instrument), omission (fail to scan the pertinent instrument at the right time) and emphasis (fail to cross check the instruments and use information from single instrument) [2]. Results by examinees E and F indicate some of these three scanning errors.

The following are some comments made by examinee A after the test.

a) There are some instruments that give us the same information. Scanning the proper instrument is one of the important ways to perform the IFR efficiently.

b) If the pilot knows the amount of the bank angle when performing the standard rate turn, he can only look at the bank index in the AI and he does not need to scan the turn coordinator during the turn.

c) If the pilot knows the engine rpm and the pitch angle to perform the constant rate of climb, he does not need to scan the AS and the VSI during the climb.

3 Flight Tests - IFR-

Since the tests in the previous section have been conducted by the flight simulator, there is a possibility that differences exist between the results obtained by the flight simulator and those by an actual airplane. In this section, measurements of the pilot's eye-scanning were made during an actual single-engine light airplane flight under IFR. The straight and climb flight and the VOR interception flight were tested. Comparisons with simulator tests were also done.

3.1 Experimental Apparatus and Methods

3.1.1 Flight Test Apparatus

A single engine light airplane (CESSNA 172) was used for the flight test. It is a type C172H made in 1967. The aircraft descriptive data are 4 pilots/passengers, max. engine power 145HP, gross weight 2300lbs, max. speed at sea level 120kts, and range 517n.mile at 7000ft.

The examinee who attended the test has a FAA CFII (certified instrument flight instructor) license. His flight time was 900h.

An eye-mark recorder (NAC, EMR-7) was used to record the examinee's eye movement. A handheld digital VCR was used to record the output from the eye-mark recorder. The example of the picture recorded by the eye-mark recorder is shown in Fig.5. The + sign on the turn coordinator indicates that the pilot is currently looking at this instrument.

3.1.2 Experimental Methods

The flight tests were conducted in the airspace near Camarillo airport (CMA) located 50n.mile northwest of Los Angeles. As for the VOR interception flight, San Marcus VOR (RZS) located 40n.mile northwest of CMA was used as a target VOR. Weather was CAVOK during the test.

During the flight test, another pilot who has a FAA CFI license was in the co-pilot seat acting as a safety pilot. The examinee was in the left seat wearing the eye-mark recorder. Since the recorder prevented him from wearing an instrument training hood that enables the pilot to simulate an instrument methodological condition, the examinee was asked to fly the airplane without looking outside the airplane as much as possible. The operator of the eye-mark recorder was on board in the passenger seat.

The eye-mark recorder has to be calibrated so that the position that the examinee is currently looking at coincides with the output position from the recorder. This calibration was done using the instrument panel while the examinee is looking at the center of the AS, AI and VOR before the engine is started. The examinee was asked not to move his head as much as possible until he begins to fly to avoid the calibration to be out of position. Therefore, the safety pilot controlled the airplane from the parking spot until it reached 500ft AGL after take-off. The calibration was repeated at a run-up area just before the take-off.

Two flight scenarios were used in this flight test. First scenario was a straight and climb IFR flight from 1000ft MSL to 1400ft MSL. The examinee flew the airplane with maximum power, maintaining a heading of 250°, an air speed of 85kts and a climb rate of 400ft/min for one minute. The second scenario was a VOR interception to RZS VOR radial 095 maintaining an altitude of 4500ft MSL and an airspeed of 100kts from a heading of 350° to 265° for about 80sec.

The instruments that the examinee was looking at were analyzed from the video-recorded data in 30Hz. The air speed, altitude, heading, bank angle and pitch angle shown on the instrument panel were read from the same video recorded data in 3Hz. Since the instrument pictures in the video recorded data are very small, there were some difficulties in reading these amounts, therefore some errors may exist in these data.

3.1.3 Flight Simulator

The same examinee conducted the flight simulator tests to clarify the difference between the actual flight and the flight simulator test. The PC-based flight simulator with IFR training software Jeppessen FS100 was used. The flight scenario of the flight simulator test was almost the same as the first scenario of the actual flight. Wind and turbulence were not added to the scenario.

3.2 Results and Discussion

3.2.1 Straight and Climb Flight

Figure 6a shows the scanning ratio of each instrument during the straight and climb flight. This figure shows that the examinee is mainly scanning the AI, AS and HDG. Figure 6b shows the scanning patterns that indicate how the examinee moves his eye from one instrument to another. The number in this figure indicates the frequency of eye movement in percentages. This shows that the examinee mainly moves his eye among the AI, AS, ALT and HDG. These four instruments are the so-called basic “T”-configuration [3]. The examinee is maintaining the airplane attitude by scanning among the “T”-configuration instruments as suggested in the textbook.

3.2.2 VOR Interception

Figure 7a shows the scanning ratio of each instrument during the VOR interception test. This shows that the scanning ratio of the AS and AI has decreased when compared with the results in Fig. 6a. He mainly scans the HDG and VOR. According to the scanning patterns in Fig.7b, the frequency of the “T”-configuration scanning has decreased. Figure 8 shows the VOR interception flight path in the horizontal plane that was estimated from the data of the bank and heading angles. During this interception flight, the bank angle changed from about 6° to 15° and then finally 7°. This flight is divided into three flight regimes, A, B and C, according to these bank angles. Table 2 shows the scanning ratio at each regime. This table indicates that the scanning ratio at regime A resembles the scanning ratio in Fig.7b. However, in regime B, the scanning ratio to the VOR decreases. In regime C, the examinee is mainly scanning the AI and HDG.

3.2.3 Straight and Climb Flight by Flight Simulator

Figure 9a shows the scanning ratio of each instrument during the flight simulator test. This shows that the scanning ratio of the HDG has increased compared with the results in the actual flight in Fig.6a. The scanning patterns in Fig.9b indicate that the examinee is mainly scanning the "T"-configuration instruments but the scanning movements between the HDG and AI are very high. This result indicates that it is possible for the pilot to fly the airplane in the flight simulator mainly by scanning the HDG without taking care of the climb rate, as long as, the airplane elevator trim is correctly adjusted and the airplane is flying at a constant rate of climb. This may be because the airplane attitude does not change due to the turbulence from outside in the flight simulator. In an actual flight, since the airplane experiences turbulence without notice, it is always necessary for the pilot to scan the entire instrument. Therefore, the way of scanning for the actual flight is different from that for the flight simulator. When the test is conducted using the flight simulator in this section, the examinee should try to fly the airplane with a consciousness that he is flying an actual airplane.

4 Flight Tests - VFR-

When flying under VFR, the pilot eye scanning will be totally different from that of the IFR flight. In this section, differences in pilot eye scanning between the IFR and VFR are discussed by conducting a VFR flight test.

4.1 Experimental Apparatus and Methods

The airplane and the eye mark recorder used in section 3 are also used here. The same examinee as in section 3 attended the VFR test. Figure 10 shows the example of the picture recorded by the eye-mark recorder during the test.

The flight test was conducted in the traffic pattern at the CMA airport. Measurements were done during the touch and go flight in the left traffic pattern of Runway 26. The runway is 6000ft in length and located at 75ft AGL. The standard altitude of the traffic pattern is 875ft MSL. While flying in the final leg, the sunshine did not allow the eye-mark recorder to operate correctly. Therefore, the pilot eye movements were recorded only while the airplane flew in the left downwind and the left base.

4.2 Results and Discussion

Figure 11 indicates an example of the path of the VFR traffic pattern flight. It was drawn using the video recorded data as in Fig.8. The flight tests were conducted twice. The flight from the left downwind to the base leg is divided into three flight regimes A, B and C. Regime A corresponds to the downwind leg, B the turning base leg and C the left base leg.

Figures 12a and 12b show the scanning ratio of each instrument and the scanning patterns in regime A. These show the examinee is mainly observing the outside of the airplane through the windshield. The examinee scans the AS, AI and engine RPM at a relatively high scanning rate.

Figures 13a and 13b show the results of regime B. Since the airplane is turning to the left, the examinee looks at the front side and the left side of the windshield. The examinee often scans the AS and the turn coordinator.

Figures 14a and 14b are the results of regime C. Since the airplane is going to turn to the final, the examinee is looking at the runway (left side) and the AS in turn. He observes the AS frequently to avoid the aircraft from stalling.

The scanning ratio of the AI and the HDG when conducting the IFR flight were relatively high as was shown in Figs.6a and 6b, because the AI acts like outside scenery during the IFR flight. The pilot under VFR can maintain the present heading only by looking outside, but the pilot under IFR has to scan the HDG to keep the present heading. As noted in Fig.6b, the examinee under IFR mainly scans the "T"-configuration instruments. On the other hand, the examinee under VFR scans only the instruments that are needed at a specific flight situation.

5 Conclusions

In this paper, tests were conducted both by a flight simulator and by an actual flight to investigate how a pilot flies an airplane by effectively utilizing the instrument information obtained by eye scanning. The differences between IFR and VFR flights are also discussed.
(1) Flight simulator tests were done by several examinees with different flight experiences. Experienced pilots fly the airplane with an attitude instrument flying technique that mainly utilizes the information from the primary instruments.
(2) Actual IFR test results indicated the importance of the eye scanning over the basic T-configured instruments. Similar results cannot be obtained between the flight simulator and the actual flight, unless the examinee flies the flight simulator with a consciousness that he is flying an actual airplane .
(3) Actual VFR test results indicated that the pilot can fly the airplane safely as long as he scans the proper instruments that are needed at a specific flight situation.

Acknowledgments

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[2] *Instrument/commercial manual*, Jeppesen Sanderson, Colorado, 1988, pp.1-19-1.21.
[3] Ref. 2, pp. 1-22-1.35.

Table 1 Examinee's Data JCAB : Japan Civil Aviation Bureau

Examinee	License & Rating	Flight Time	Note
A	JCAB airline transport pilot (multi-engine, instrument rating)	3500 h	Boeing747 Airline Pilot
B	FAA commercial pilot (multi-engine, instrument rating)	650 h	Fixed Wing 250h No flight experience for the last one year
C	JCAB commercial pilot (multi-engine, instrument rating)	290 h	Under training as an Airline Pilot
D	FAA private pilot (single-engine, instrument rating)	200 h	No flight experience for the last one year
E	FAA private pilot (single engine)	50h	No flight experience for the last two years
F	non-pilot	0h	undergraduate student

Table 2 Scanning Ratio (VOR Interception Flight)

	A (%)	B (%)	C (%)
AS	0.0	3.1	6.6
A I	2.6	17.5	28.0
ALT	2.0	10.3	8.0
TCD	0.0	10.3	8.4
HDG	43.7	31.2	29.2
VSI	6.7	13.4	9.3
VOR	44.9	14.3	10.5

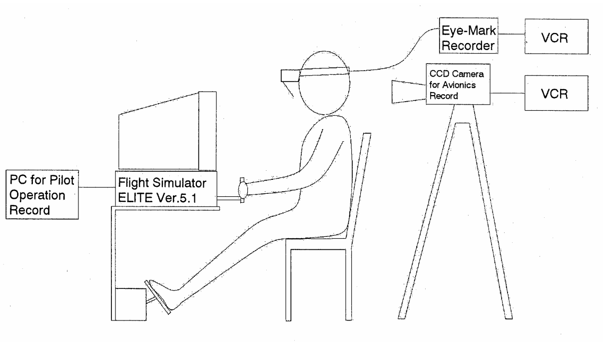

Fig.1a) Experiment Block Diagram

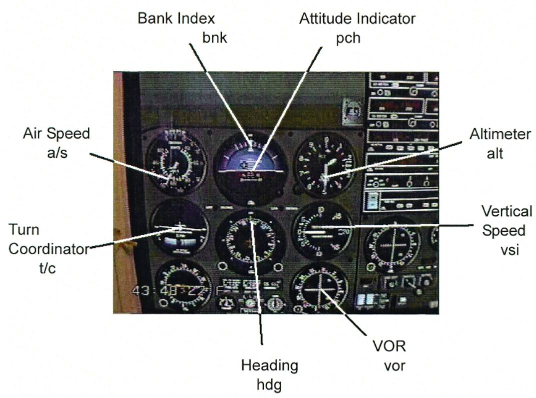

Fig.1b) A Picture of a Flight Simulator Recorded by Eye-Mark Recorder

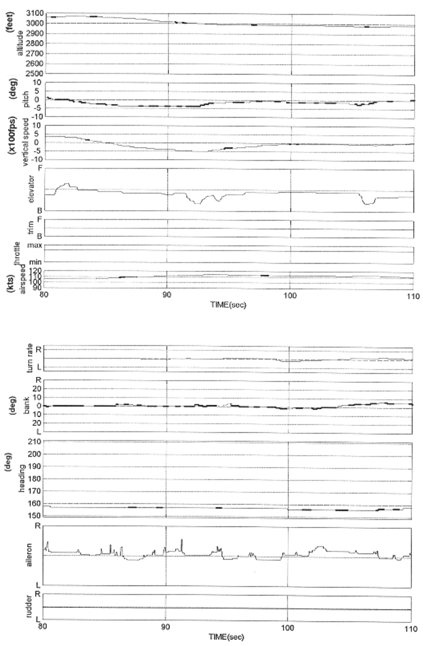

Fig.2 Time Histories of Flight Parameters for Straight & Level Flight (Pilot A)

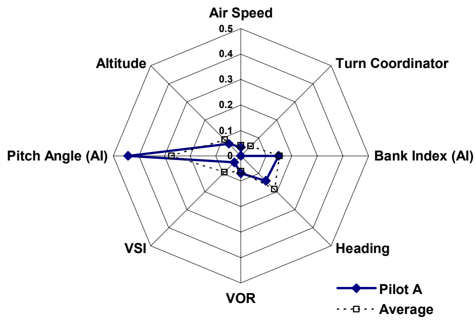

Fig.3a) Pilot A

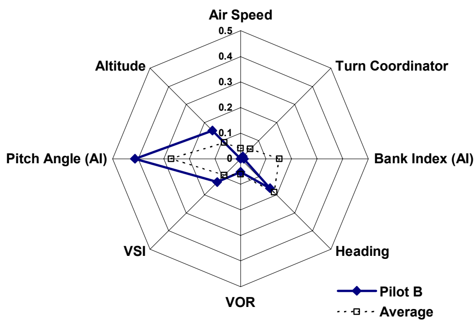

Fig.3b) Pilot B

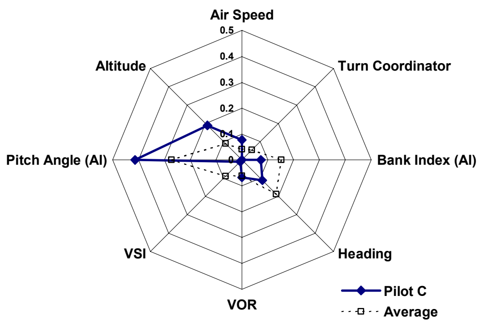

Fig.3c) Pilot C

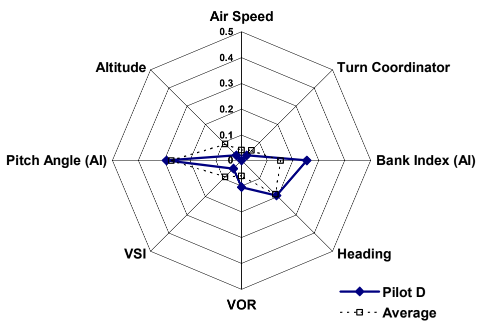

Fig.3d) Pilot D

Fig.3 Scanning Ratio of Each Instrument (Straight & Level Flight)

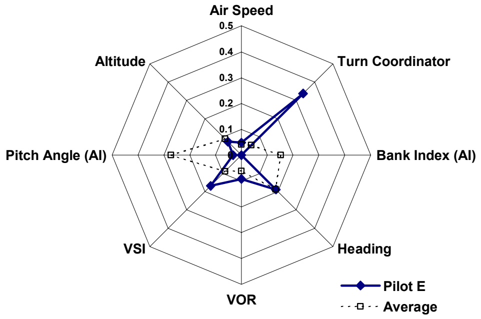

Fig.3e) Pilot E

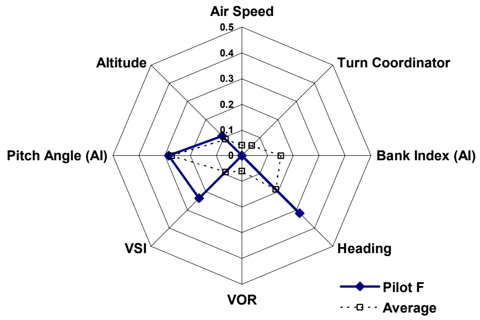

Fig.3f) Pilot F

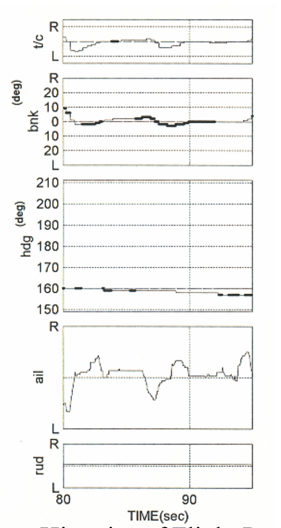

Fig.4 Time Histories of Flight Parameters for Straight & Level Flight (Pilot D)

Fig.5 View from Eye-Mark Recorder during IFR Flight Test

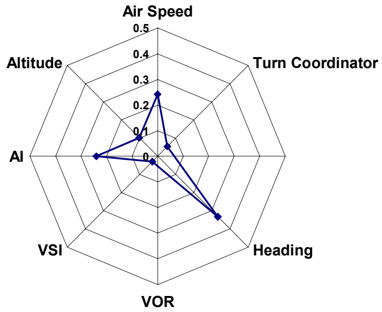

Fig.6a) Scanning Ratio of Each Instrument

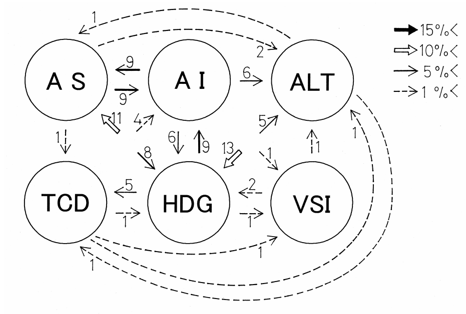

Fig.6b) Scanning Patterns
Fig.6 Straight & Climb Flight

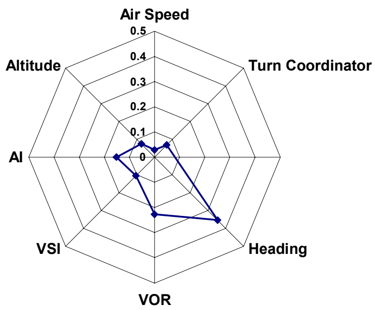

Fig.7a) Scanning Ratio of Each Instrument

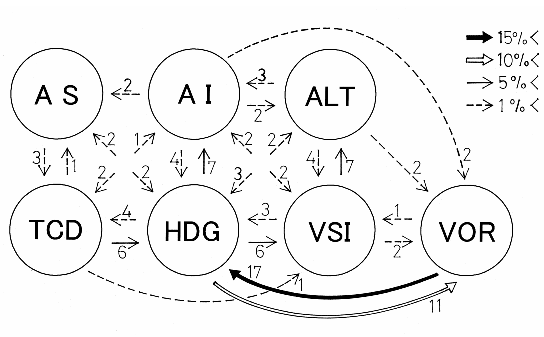

Fig.7b) Scanning Patterns
Fig.7 VOR Interception Flight

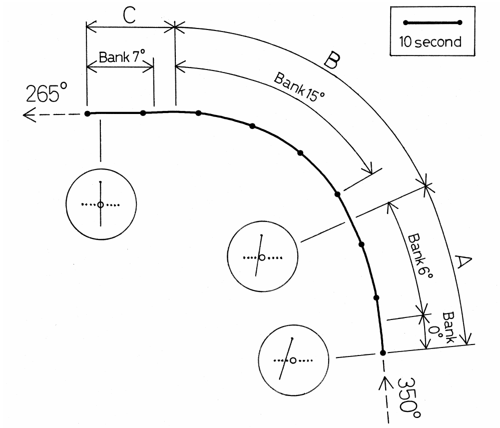

Fig. 8 VOR Interception Flight Path

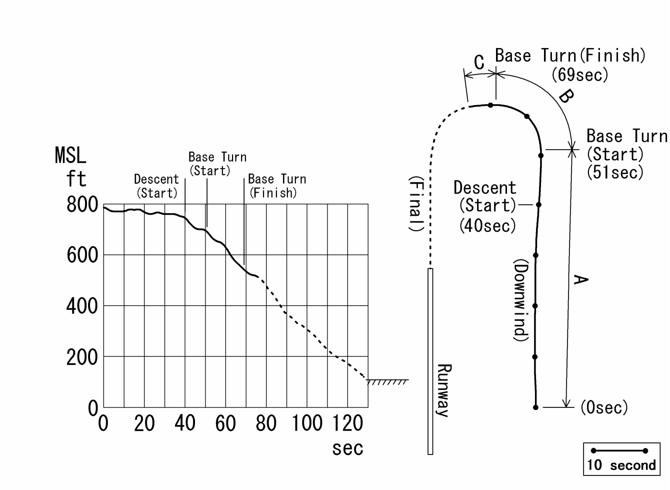

Fig. 11 Flight Path in the Traffic Pattern

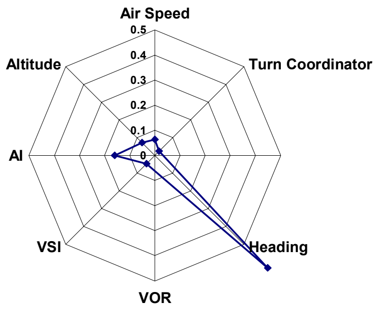

Fig.9a) Scanning Ratio of Each Instrument

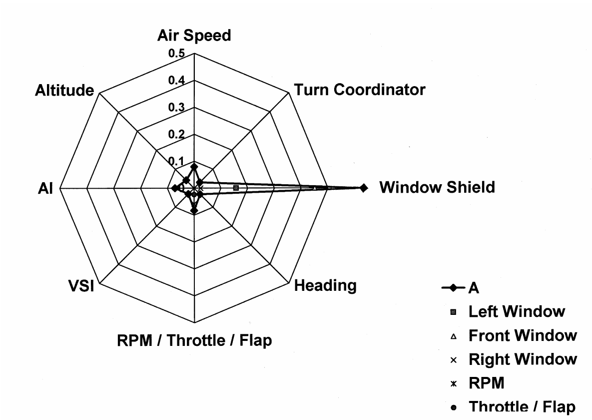

Fig.12a) Scanning Ratio of Each Instrument

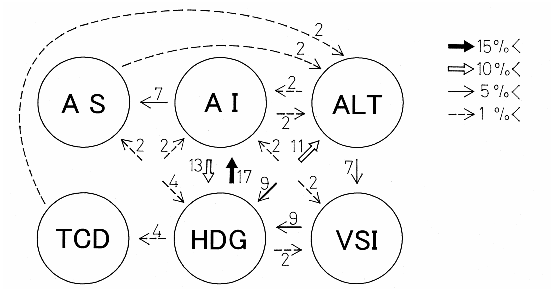

Fig.9b) Scanning Patterns
Fig.9 Straight & Climb Flight, Flight Simulator

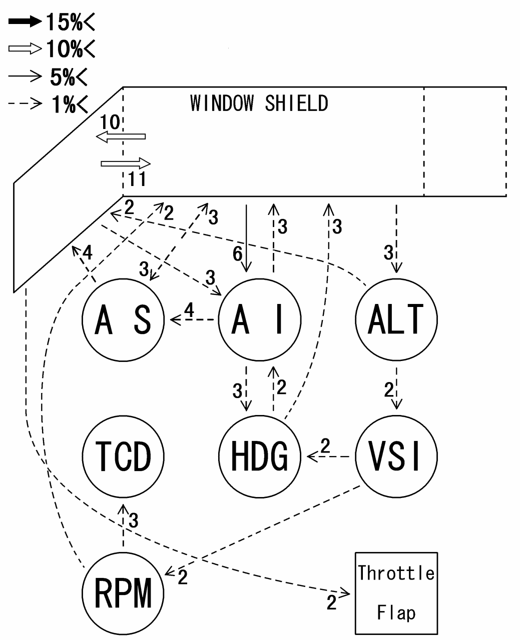

Fig12b) Scanning Patterns
Fig.12 VFR Flight Test (A: Downwind)

Fig.10 View from Eye-Mark Recorder
during VFR Flight Test

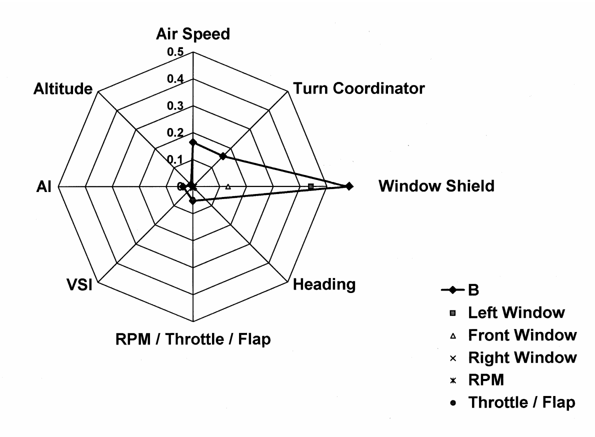

Fig.13a) Scanning Ratio of Each Instrument

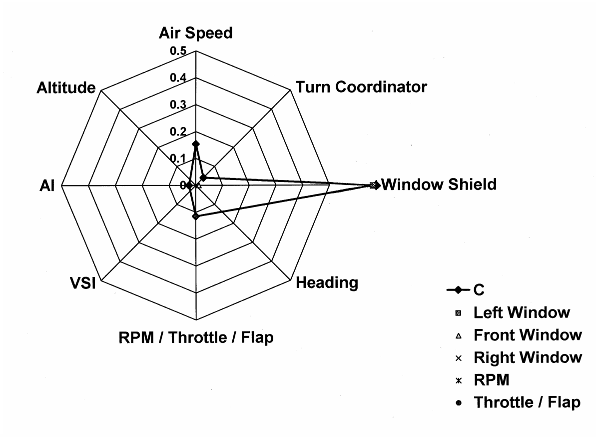

Fig.14a) Scanning Ratio of Each Instrument

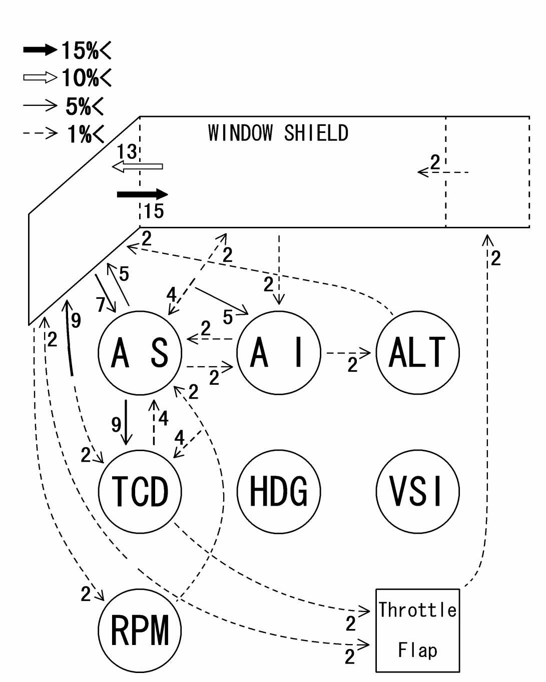

Fig13b) Scanning Patterns

Fig.13 VFR Flight Test (B: Base Turn)

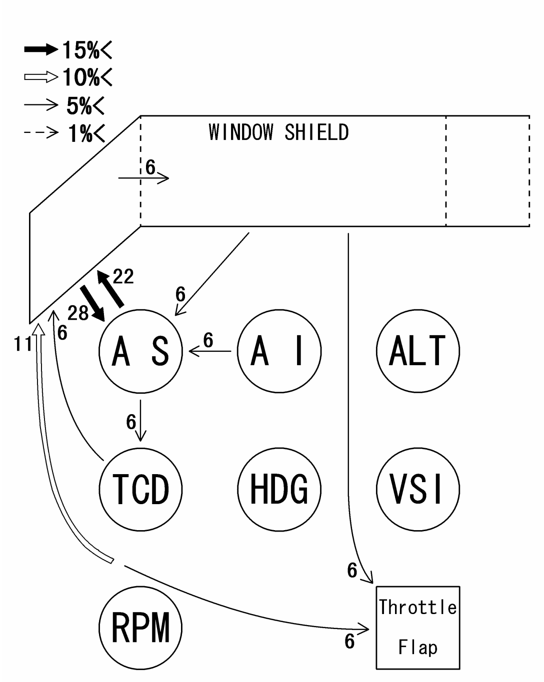

Fig14b) Scanning Patterns

Fig.14 VFR Flight Test (C: Left Base)