REPORT 365

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ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT
64 RUE DE VARENNE, PARIS VII

APRIL 1961

THE USE OF PILOTED FLIGHT SIMULATORS IN GENERAL RESEARCH

by

G. A. RATHERT, Jr., B. Y. CREER and M. SADOFF

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NORTH ATLANTIC TREATY ORGANISATION

62-08-5069

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This Report is one in the Series 334-374, inclusive, presenting papers, with discussions, given at the AGARD Specialists' Meeting on 'Stability and Control', Training Center for Experimental Aerodynamics, Rhode-Saint-Genèse, Belgium, 10-14 April 1961, sponsored jointly by the AGARD Fluid Dynamics and Flight Mechanics Panels

SUMMARY

Recent research on a number of general flying-qualities problems is reviewed in order to discuss the use of piloted simulators and their validity. Direct comparisons between different types of simulators and actual flight tests are used to show which information cues to the pilot are required in each of several basic problem areas, of advanced transports and spacecraft, where the use of simulators might be particularly desirable.

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THE USE OF PILOTED FLIGHT SIMULATORS IN GENERAL RESEARCH

George A. Rathert, Jr., Brent Y. Creer and Melvin Sadoff*

1. INTRODUCTION

The objective of this paper can be described more clearly by referring to the functional outline of a piloted simulator as shown in Figure 1. All simulators are similar in principle; pilot control inputs are fed to an analog computer to compute the vehicle motion response which is then presented back to the pilot by some combination of visual and motion cues. The key process in any effective piloted simulator is the mental extrapolation by the pilot from the behavior of the simulator to actual flight conditions. The value of this extrapolation depends on the selection of each element of the simulation procedure; the pilot, the mechanical cockpit and controls, the method of handling the equations in the computer, and the presentation of the vehicle response to the pilot. With experienced research teams using six-degree-of-freedom equations in the computer the major differences in technique involve the latter item and this is what we wish to discuss - the selection of the visual and motion cues needed for accurate study of the pilot control problems expected to be most significant for advanced transports and spacecraft.

If the research is to provide meaningful design criteria, quite stringent requirements must be imposed on the accuracy and assurance of the pilot's extrapolation process. His behavior must be realistic enough to justify not only his own subjective opinion, but also measurements of performance and sometimes even physiological condition. In research on conventional aircraft we have been fortunate to be able to verify the quality of this extrapolation directly by giving the test pilots frequent opportunity to compare identical problems in flight and on the simulator, both to keep their impressions of the simulator calibrated and to check our choice of equipment.

For less conventional vehicles, such as supersonic transports or spacecraft, such directly comparable flight experience will not be available. If the major problems are to be solved before the vehicles fly, the research pilot must extrapolate to conditions he has never actually experienced. In such cases, it appears necessary to identify probable problem areas and then search the past experience in these areas where direct comparisons have already been made in order to see what visual and motion cues are likely to be critical and what techniques are likely to be most useful. Based on simple preliminary simulations, the problem areas of minimum dynamic stability, control-system sensitivity, and cockpit instrument display of vehicle attitude have been selected for this paper. Since this paper is essentially a brief summary of just the correlation aspects of many different research programs much discussion of the individual experiments had to be eliminated. Only the discrepancies of particular interest will be considered. The individual reports referred to in the text contain much more detailed results for each item and should be read directly if it is desired to use the charts in a quantitative sense.

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2. DISCUSSION

2.1 Dynamic Stability

2.1.1 *Longitudinal*

Longitudinal dynamics will be considered first. Figure 2 illustrates the type of aircraft design criteria usually obtained from a simulator study[1]. The short-period dynamic response parameters significant to the pilot are the stability, shown as the ordinate, and the damping, shown as the abscissa. The solid lines show the boundaries of regions of constant pilot opinion, that is, combinations of stability and damping in upper region are all satisfactory, in the middle region, unsatisfactory, and in the lower region, unacceptable. The item of concern is the penetration of the 'minimum acceptable for emergency operation' boundary into the unstable region. In view of the performance penalties usually associated with providing aerodynamic stability and damping, the need for accuracy in locating this boundary need not be labored. Therefore, as a check, this study was repeated in flight on a variable-stability airplane and on two other types of simulators.

Since showing all four sets of boundaries would make one figure too confusing, the comparison will be shown here at only one cross section of Figure 2 - the variation of pilot opinion with damping at a constant level of stability. This is shown in Figure 3. (Additional comparisons are presented in Reference 1.) As the level of damping decreases, the pilot opinion deteriorates from 'satisfactory' to 'unacceptable.' The adjective ratings have been augmented by the pilot's numerical rating system actually used in the tests, which is shown in Figure 4 and is explained in Reference 2.

The flight test data represented by the solid line are compared with data for three simulators differing in the number and type of motion cues. The broken line repeats the previous data for the centrifuge shown in model form in Figure 5. This device has three degrees of freedom: a pitch gimbal, a roll gimbal, and angular rotation of the arm to produce a centrifugal force. The center line symbol indicates data for the device shown in Figure 6, a moving cockpit with two axes of angular rotations only - in this study pitch and roll. The short dash line is for a fixed cockpit simulator, typified by Figure 7. There is no real motion input; the pilot has just the instrument display.

Returning to the correlation, Figure 3, the first thing to observe is that the qualitative comparison between all four devices is quite satisfactory. However, there is a quantitative discrepancy in the regions of low damping and stability near the 'unacceptable' boundary that is likely to be of most interest to the investigator. The pitch-roll chair agrees well with flight, but the fixed simulator and the centrifuge are significantly conservative or rated more difficult to fly and these two cases were examined.

The explanation of the fixed-simulator results is quite direct, the angular acceleration is an important cue the pilot uses to obtain anticipation or lead in his response (see Reference 3, for example). In a stressful problem, he apparently does not acquire this information as well through a visual instrument as through the seat of his pants and, therefore, finds it more difficult and unrealistic to cope with an unstable or lightly damped vehicle in a fixed simulator.

The difficulty with the centrifuge arises from the necessary use of the cab gimbal system to rotate the pilot in order to position him properly with respect to the centrifugal-force vector used to provide the normal acceleration input. The desired linear normal accelerations were correctly matched with flight but, in view of the limited number of mechanical freedoms available, this had to be done at the expense of introducing exaggerated angular accelerations in pitch and spurious fore and aft accelerations and these false inputs apparently disturbed the pilot for accelerations below about 3g. This is a fundamental problem in the use of centrifuges as closed-loop piloted simulators (see, for example, Reference 4) and the only feasible solution appears to be to provide more mechanical degrees of freedom and then empirically search for the combinations of gimbal motions that least disturb the pilot in a given problem. In the pitch-roll chair which provided the most accurate comparison with flight, the two gimbals matched the desired angular accelerations to the limits of the frequency response of the drive system since this was their only function. Incidentally, this problem with the centrifuge has led to the construction at the Ames Research Center of the five-degree-of-freedom device shown in Figure 8. A three-gimbaled cab and vertical translation as well as the centrifuge rotation will be provided.

Despite the correlation problems, the pilots insisted that they got a better feel for the control problems in the centrifuge simulation, indicating further consideration if it is desired to study vehicles intended to operate in a high g field - for instance, manned re-entry or high-speed flight at low altitude. The centrifuge program was extended to 5g and 7g and a significant shift was found in the pilot opinion boundaries for design criteria of the type just shown. Figure 9, from Reference 5, shows the effect on the flying qualities of a re-entry vehicle as one example. Since the variable-stability airplane could not be operated at these g-levels for direct comparison, two additional techniques to obtain useful simulator data to supplement the pilot opinions will be discussed.

The first, measurement of pilot performance, is shown in Figure 10. The pilot's performance in a standardized tracking task is plotted as a function of acceleration force for a well damped vehicle, a fairly easy control task, and again for a lightly damped vehicle that was more difficult to fly. Data are shown for three different directions of the acceleration force - in the pilot's vernacular, eyeballs down, eyeballs out, and eyeballs in. The acceleration force has very little effect on the pilot's performance in the well-damped vehicle, but there is a very marked reduction in his ability to track with the lightly damped vehicle that obviously must be accounted for before determining design criteria in this area with simulators lacking an acceleration force input.

Now it may be noted that as far as any analysis based on performance measurements alone is concerned, there appears to be little choice as to the direction of the acceleration force; the eyeballs-in and eyeballs-out data show the same decrement in tracking. This introduces another simulator technique, the use of physiological measurements. In Figure 11 are shown comparative time-histories of the electrocardiogram, respiration, tracking score, and acceleration force for the two directions, eyeballs in and eyeballs out. It is apparent from a comparison of the two respiration traces that the direction of the acceleration force has a significant deteriorating effect on the pilot that would not have been observed from the tracking score alone. Performance measurements are useful but very often, because of the extreme adaptability of the test pilot, they have to be supplemented with additional data. Details of the physiological instruments and further results are presented in References 6, 7 and 8.

2.1.2 Lateral

The lateral dynamics are considered next. Figure 12 again shows a typical plot of the dynamic response parameters used for vehicle design criteria; the ordinate is the roll control power, increasing in the vertical direction, and the abscissa is the roll damping, decreasing from left to right. These data are from the study reported in Reference 9. Pilot opinion is indicated by boundaries defining the combinations of these two parameters regarded as satisfactory, unsatisfactory, and unacceptable. In this case, direct comparisons were made between flight, the moving simulator which rotated about the roll and the pitch axes, and a fixed simulator with only a cockpit instrument presentation.

In the satisfactory region, which unfortunately included nearly all of the airplanes available for flight testing, the comparison was, as usual, generally good for all three sources. For the boundary between the unsatisfactory and the unacceptable regions, there were significant differences between the two types of simulators in two instances.

In the general region of very high control power and low damping, the pilot rated the configurations unacceptable because he was unable to maintain precise control of a rolling maneuver. The fixed simulator here is unconservative; that is, it is easier to control than the moving cockpit. A study revealed two related effects. In the first place, as the damping falls off as far as the pilot is concerned the aircraft changes from a roll-velocity control device to a more difficult roll-acceleration control device. To effect a change in his steady angle of bank, the pilot must execute first an upsetting aileron motion and then a precise time restoring motion rather than a simple pulse. This is illustrated in Figure 13. In the second place, the roll control power is very large in this region, compounding any control sensitivity problems by inducing extremely large angular velocities and angular acceleration forces on the pilot. The differences between the fixed and moving simulators are felt to be due to the effects of these forces on the pilot's physical ability to execute the more complicated control motion shown in Figure 13. It is inferred that the actual motion cues would be absolutely necessary to reproduce the flight environment in this region.

The other instance where the two types of simulators did not agree was for the combination of low control power and low damping. In this case, the fixed simulator was conservative, that is, more difficult to fly. It was found that in trying to cope with a highly damped vehicle with minimum control power, the pilot needed the anticipation or lead provided by the angular acceleration input. He again apparently did not acquire or use this information as well through visual means as through the seat of his pants.

2.1.3 Dutch Roll

Dutch-roll dynamics are considered next. This study is in progress and only partial results can be presented. Two of the vehicle response parameters being considered for design criteria are the Dutch-roll damping parameter ζ_d and the control coupling term, the effective yawing moment due to aileron N_{δ_a} . Although the flight tests on a variable-stability airplane are complete (Fig. 14), simulator data are available for a direct comparison at only one value of damping. Figure 15 shows the numerical pilot opinion as a function of the effective yawing moment due to aileron at one constant value of Dutch-roll damping so selected that the best configuration is only barely satisfactory. The comparison available is that between flight and a fixed simulator with a modified visual input. This device is shown in Figure 16. The pilot sits in a fixed cockpit inside a 20 foot diameter projection screen. A moving artificial horizon is projected on to the screen by the servo-driven projector above the cockpit which is controlled by the analog computer. We have just discussed two instances where the standard cockpit instrumentation was inadequate to present angular acceleration cues when the pilot was attempting to cope with a difficult set of dynamics. This is an effort to furnish the required angular acceleration cues without resorting to the complexity of a moving cockpit by providing a strong visual cue, through the pilot's peripheral vision.

To return to the comparison in Figure 15, the general agreement between the flight and the simulator results is quite good, indicating that the absence of actual motion cues in the simulator tests did not seriously affect pilot opinion because of the greatly strengthened visual cues presented. In the unacceptable range at large amounts of control coupling the simulator is somewhat conservative or rated as more difficult to fly. Unfortunately the reasons for this difference cannot be discussed adequately until the moving-simulator test program has been run.

2.1.4 *Combined Modes*

Each mode of the aircraft dynamics has just been examined separately. This is one of the unique advantages of a simulator - the individual modes can be isolated so that the pilot can concentrate on one problem at a time. The natural question, though, is the effect of combining the separate studies in one complete task. A study reported in Reference 10 provides some insight into this effect. In Figure 17 the numerical pilot rating for a specified vehicle and task is plotted for four levels of stability augmentation - none, light, moderate, and heavy - for two simulations, one in which only the pitch mode had the damping deteriorated, and one in which the damping about all three axes was deteriorated simultaneously.

These data indicate that where the vehicle was stable and well damped, relatively easy to control, the effect of deteriorating the damping about all three axes simultaneously did not change the pilot's rating. However, as the control problem was made more difficult by reducing the level of the stability augmentation, a very marked deterioration of the pilot opinion occurred when the pilot had to cope with a difficult problem about all three axes at once instead of just one.

2.2 Control System Dynamics

The next problem area to be considered is control-system dynamics. The basic research program available for a correlation study consisted of a series of tests on a jet fighter equipped to vary the time constant, sensitivity or stick force per g, break-out force, and deadband of the longitudinal control system. From these data[11], we have selected the comparison shown in Figure 18. The control-system response parameters considered for design criteria are the time constant, used for the ordinate, and the sensitivity expressed as the stick force per g and used as the abscissa. In this case, a slightly different technique was used in that the pilot selected three different combinations of these parameters that he considered to be the 'best available', the 'maximum' beyond which the system was too sluggish, and the 'minimum' below which the system was too sensitive. The comparison is between flight tests, indicated by the solid lines, and a fixed-cockpit simulator, indicated by the broken lines.

The comparison again is excellent and the fixed-cockpit simulation is adequate where the system has good characteristics and is relatively easy to fly. There is a very marked disagreement in the region of low sensitivity and short time constant where the system is extremely 'touchy.' The pilot complains of being on the verge of a pilot-induced oscillation or instability which is more apparent in flight than on the simulator. This apparently is another case where the feedback of the actual vehicle motion interferes with the pilot's intended control movements and the use of a moving cockpit is mandatory to simulate the flight problem.

Additional information in the control sensitivity region can be obtained by introducing another technique that is becoming increasingly useful in simulator research on pilot control problems, the mathematical model of the human pilot. It is well known that the pilot constantly changes his response characteristics in order to maintain good performance as the dynamics problem becomes more difficult. As discussed in Reference 12, this adaption process can be represented by changes in the terms of an equation or transfer function expressing his output or control force as a function of his input or error signal. Figure 19 shows the particular form of the pilot analog used in References 13 and 1 to study sensitive control systems in conjunction with piloted simulator tests. There are five parameters: a gain K_p, a reaction time τ, a lag term T_N representing neuromuscular time lag, and a first-order lead-lag network or compensation involving a lead term T_L and a lag term T_I. For this particular problem it has been found sufficient to adopt constant values of τ, T_N and T_I and vary only K_p and T_L, the form of the equation shown on the right in Figure 19.

This equation can be set up to control the simulator as indicated by the block diagram in Figure 19 and used to observe the changes in the gain and lead terms required to match the performance of the real pilot. Figure 20 shows the change in tracking score, the ordinate, as the gain K_p of the analog pilot is varied at two constant values of the lead term $T_L = 0$ and $T_L = 0.1$. The human pilot score for the identical problem is shown for reference. The situation on the left represents the control sensitivity region where the fixed-cockpit simulator was not adequate. The situation on the right represents a configuration considered easy to control.

The comparison is striking. With good control dynamics, the human pilot could have used a broad range of gain to obtain his tracking score before the appearance of any instability, which is indicated by the broken line. The use of lead is not critical. With poor dynamics, the human pilot must have had to adjust his gain closely in a very narrow band to avoid either poor performance or the instability he complained about. The use of lead or anticipation is quite critical. Also, the poor system calls for a quite low value of gain compared to the good system. It appears that the cockpit motions imposed on the pilot in flight preclude making these fine adjustments satisfactorily whereas it can be done to a certain extent in a fixed-cockpit simulator.

2.3 Cockpit Instrument Display

The final problem area to be considered is the cockpit instrument display of vehicle attitude in maneuvering flight. The particular illustration used is a study[14] of the bank angle presentation in a director-type radar display used by the pilot to track a target in maneuvering flight. Figure 21 shows time-histories of the aim error as the pilot tracked in level flight and then followed the target through an abrupt accelerated turn. Two different display principles were used: in the one indicated by the solid line, the radar scope had a line on it which always remained parallel to the true horizon like a conventional artificial horizon instrument; in the other display, shown by the broken line, the pilot was shown a little airplane symbol which maneuvered about a fixed reference in a manner analogous to the view he would get of his own airplane from a platform fixed in space some distance away.

These two displays were compared in flight, on a moving simulator with rotation about the pitch and roll axes and on a fixed simulator. In flight, there was a significant difference between the two display principles in the maneuvering portion of the flight and, in fact, one display was quite disturbing to the pilots. There is some indication of this difference from the results of the simulator that furnished two angular motion cues, but none at all from the fixed simulator. The pilots attributed their difficulties to a conflict between the visual cues received from the display and the vestibular cues from the motion of the airplane. While the relationship between the visual and vestibular stimuli that caused this effect are certainly not yet fully understood, it is apparent that even the use of a moving simulator for research on instrument displays for maneuvering flight should be approached with caution.

3. CONCLUSIONS

In summary, a number of direct correlations between flight and various types of simulators have been examined in problem areas of interest for research on advanced transports and manned spacecraft. Where the characteristics are such that the vehicle is satisfactory or easy to fly, even the simplest forms of simulation are effective. The addition of motion cues is required in two general circumstances:

(a) Where the motion cue helps the pilot by supplying a necessary lead or anticipation cue, as in coping with a lightly damped or unstable vehicle or a sluggish control system.

(b) Where the motion cue realistically hinders the pilot in making a desired control motion, as in using a very powerful or sensitive control system.

A reasonable judgment of whether such cues will be needed in a given simulation can be made by inspecting the comparisons on the design-criteria charts in the reports referenced.

If levels of acceleration stress greater than about 4g are anticipated they should be included in the simulation; however, the exaggerated or spurious motion cues encountered in closed-loop operation of a centrifuge must be taken into account.

Additional simulation techniques, such as measurements of performance and physiological condition and use of the human pilot analog, are often a necessary supplement to the subjective opinion of the pilot.

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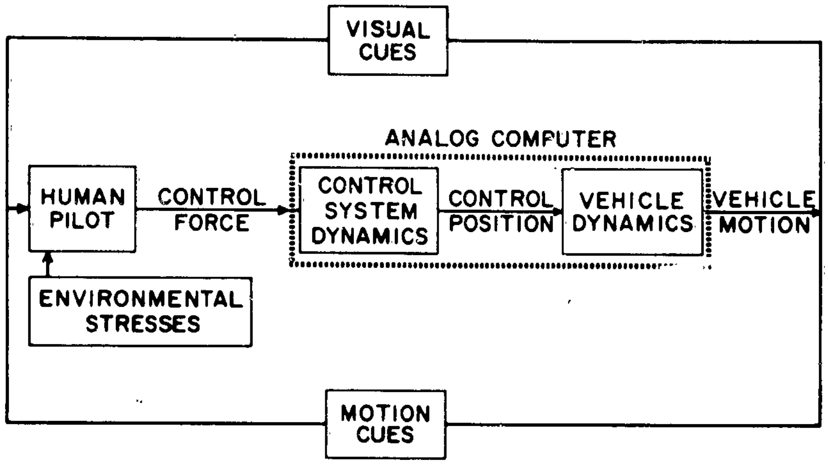

Fig.1 Block diagram of piloted simulator

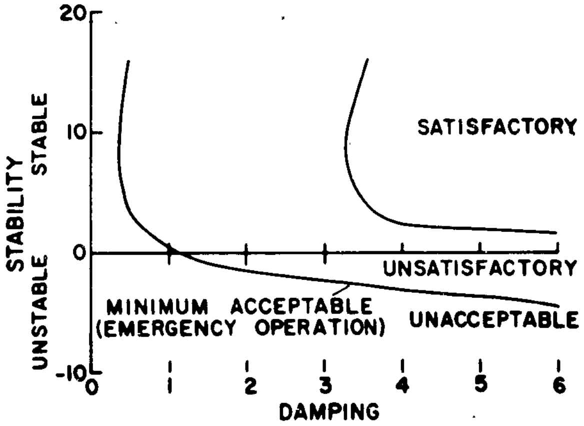

Fig.2 Evaluations of unstable dynamics with centrifuge

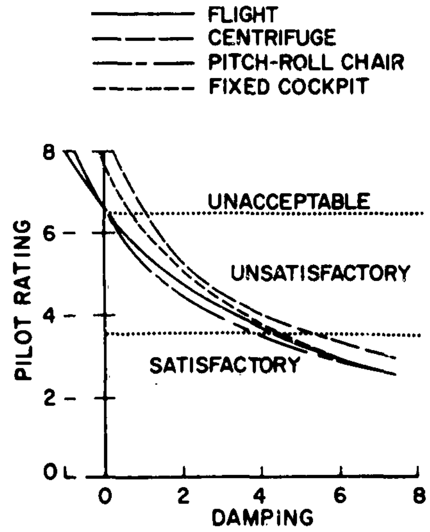

Fig.3 Effects of incomplete or spurious motion cues

[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Satisfactory	1	Excellent, includes optimum	Yes	(NOT APPLICABLE)	Yes
	2	Good, pleasant to fly	Yes		Yes
	3	Satisfactory, but with some mildly unpleasant characteristics	Yes		Yes
Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes		Yes
	5	Unacceptable for normal operation	Doubtful		Yes
	6	Acceptable for emergency condition only*	Doubtful		Yes
Unacceptable	7	Unacceptable even for emergency condition *	No		Doubtful
	8	Unacceptable - dangerous	No		No
	9	Unacceptable - uncontrollable	No		No
Catastrophic	10	Motions possibly violent enough to prevent pilot escape	No		No

*(Failure of a stability augmenter)

Fig.4 Pilot opinion rating schedule

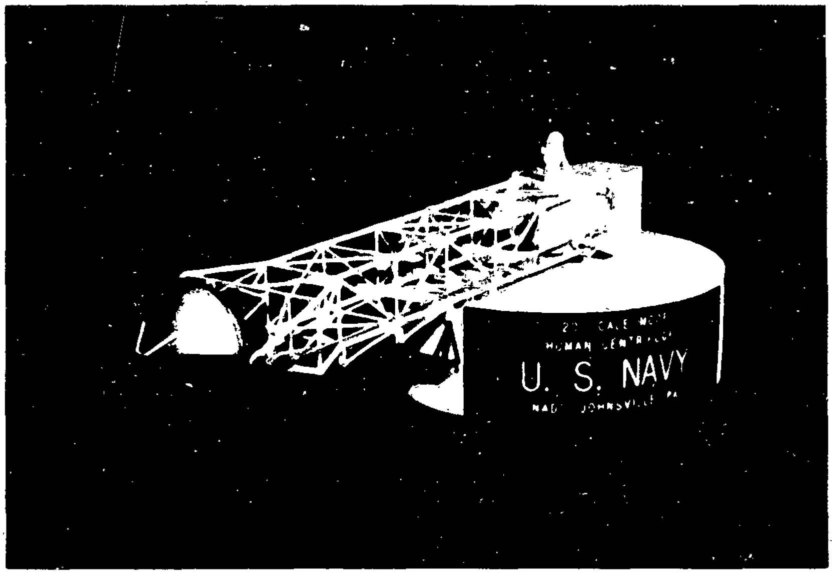

Fig.5 U.S. Navy centrifuge

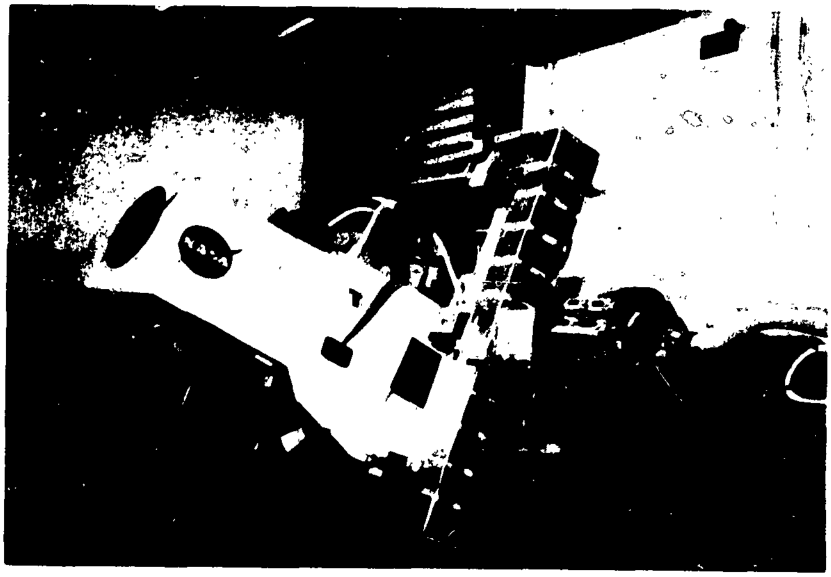

Fig.6 Ames pitch-roll chair

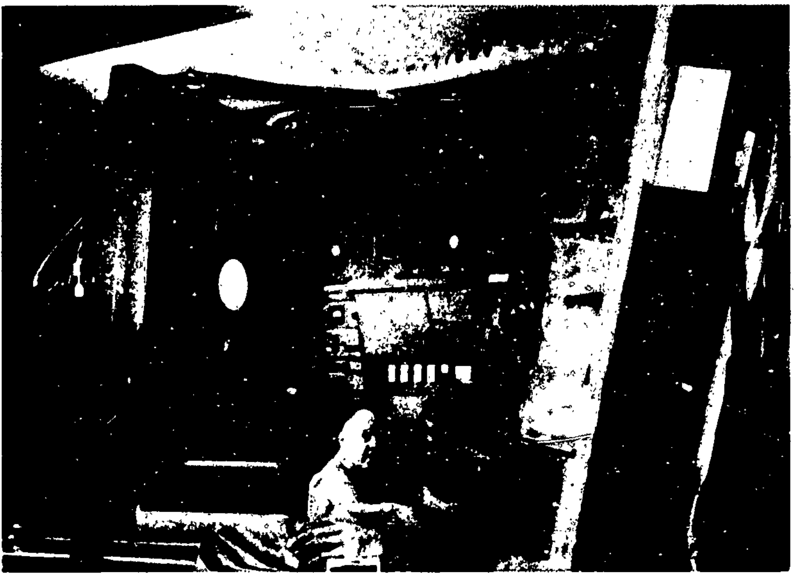

Fig.7 Typical fixed-cockpit simulator

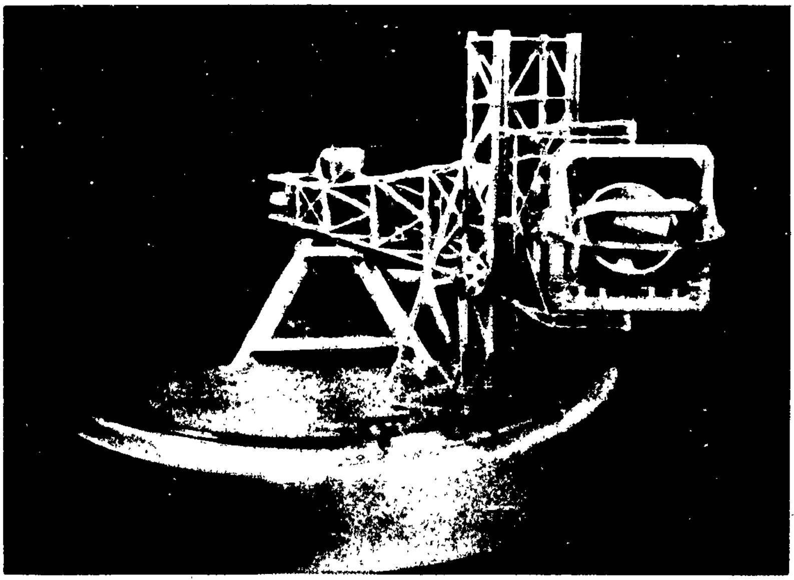

Fig.8 Ames five-degree-of-freedom simulator

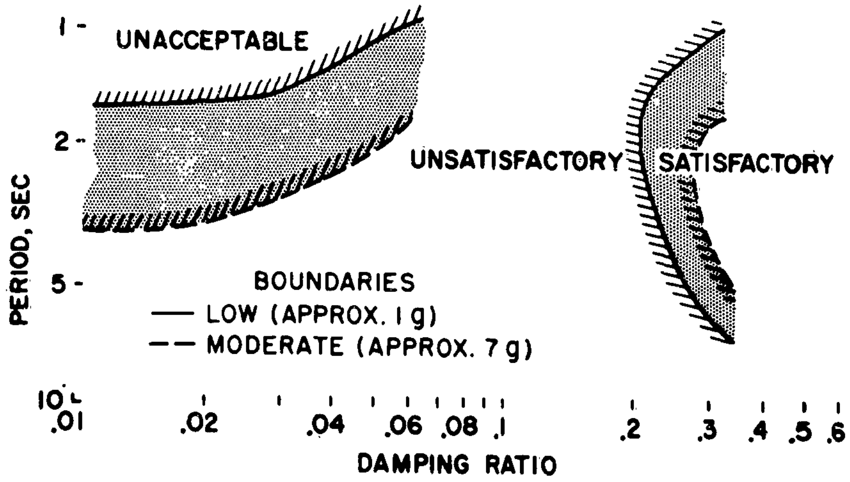

Fig.9 Effect of acceleration on pilot-opinion boundaries of longitudinal handling qualities

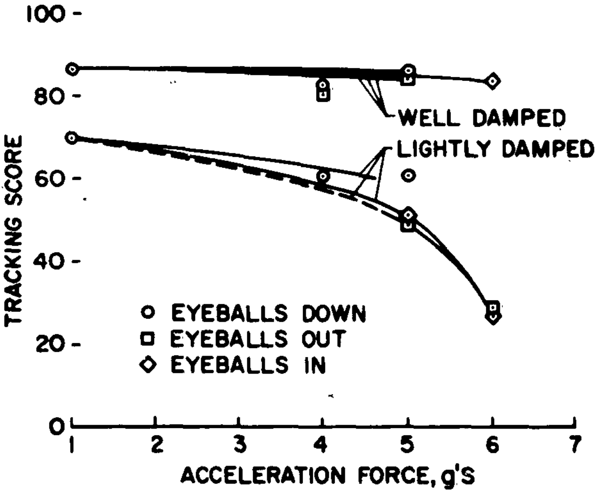

Fig.10 Effect of acceleration on pilot performance

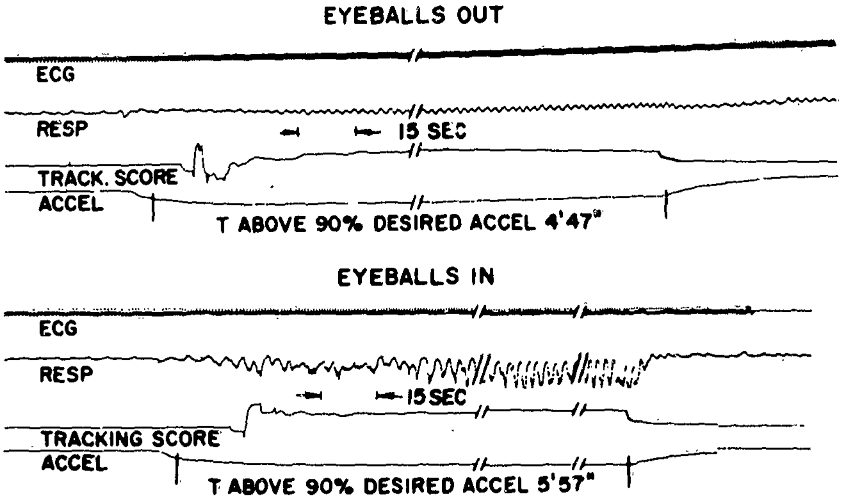

Fig.11 Physiological data

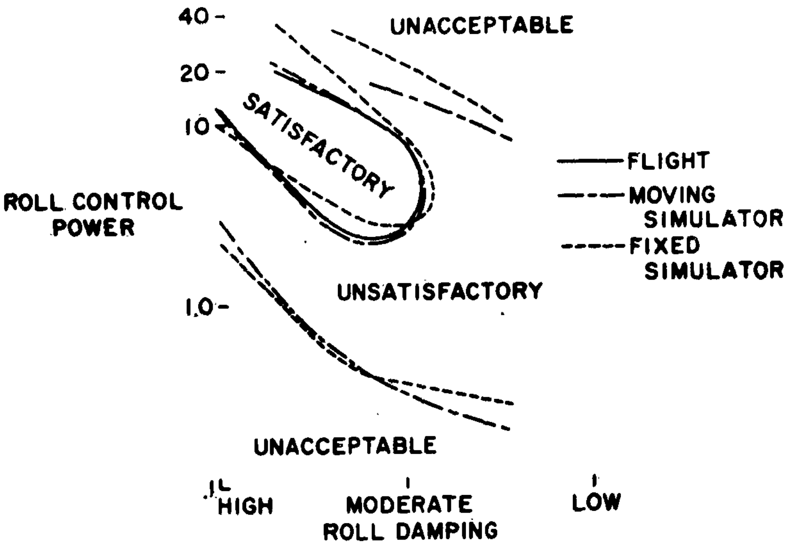

Fig.12 Lateral dynamics

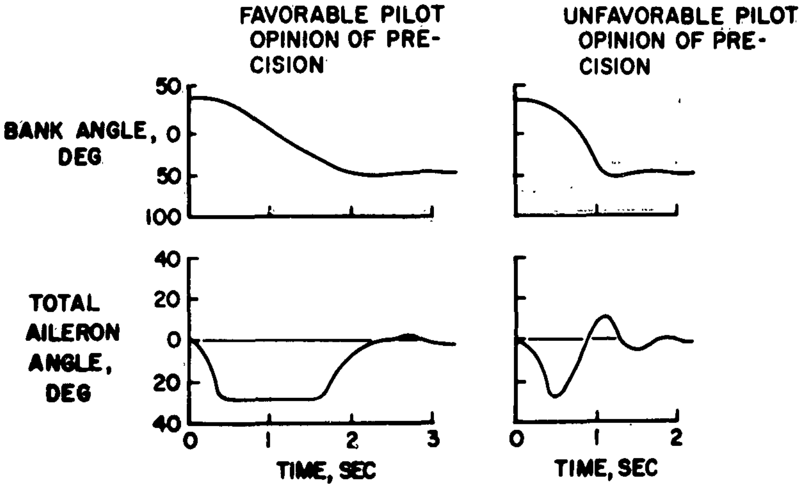

Fig.13 Observed aileron movements required for precise change in bank angle

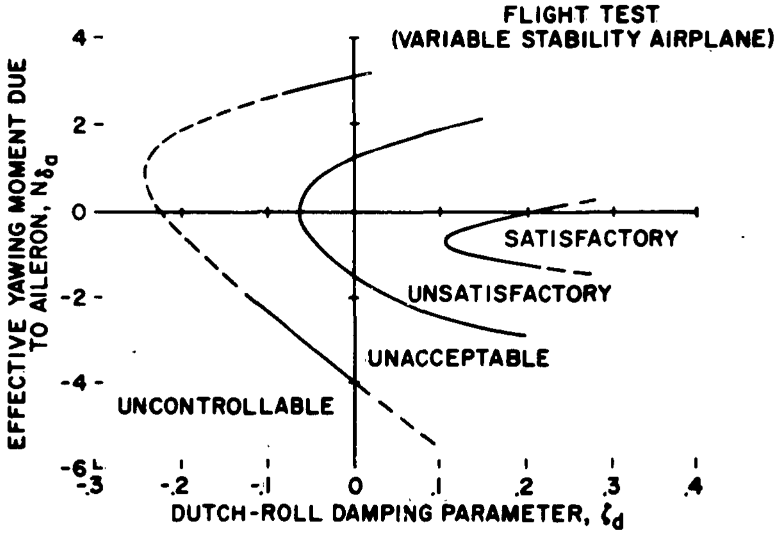

Fig.14 Lateral-directional dynamics

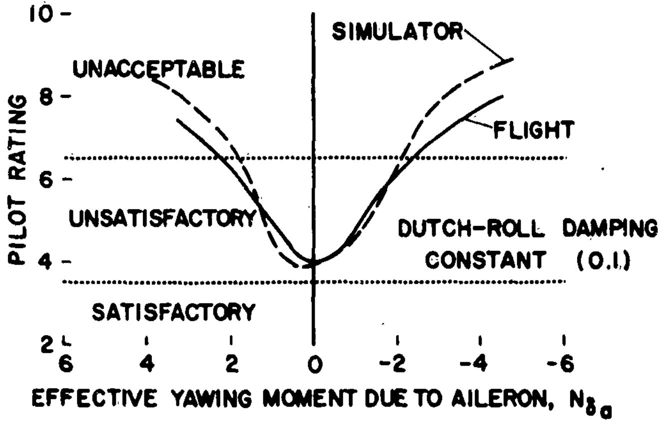

Fig.15 Lateral-directional dynamics

Fig.16 Visual environment simulator

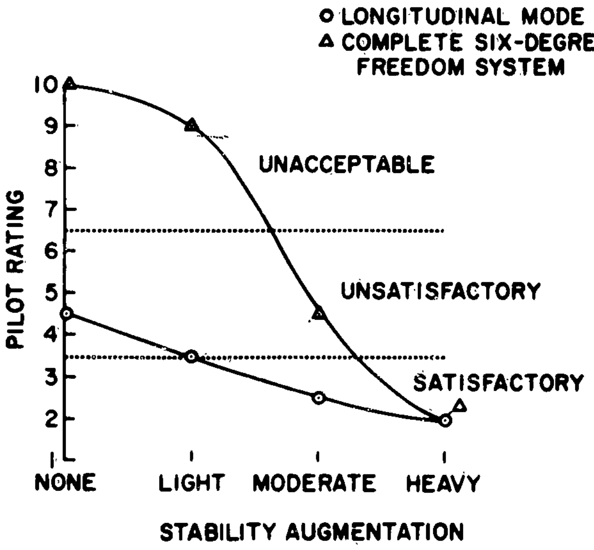

Fig.17 Effect of adding complete problem

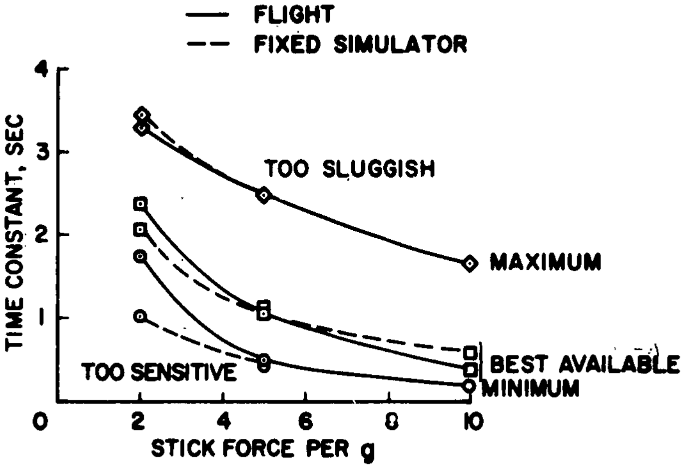

Fig.18 Longitudinal control

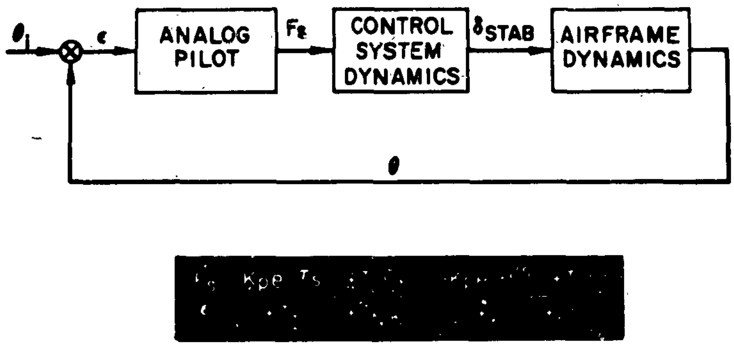

Fig.19 Simulator with analog pilot

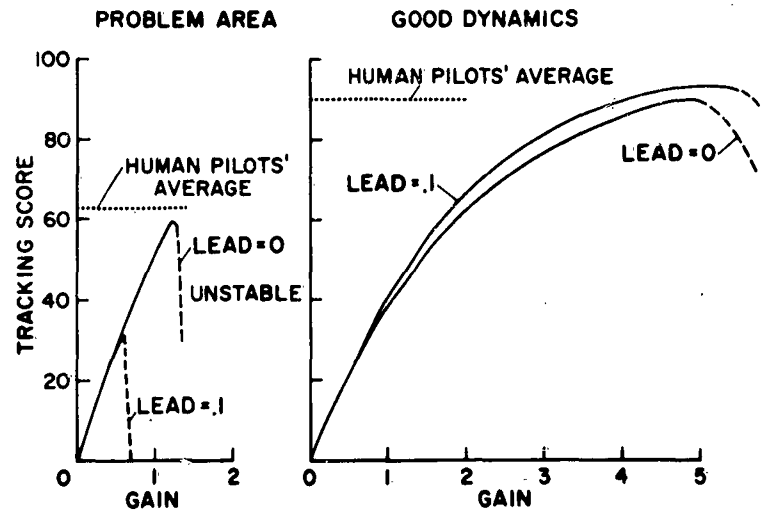

Fig.20 Typical effects of dynamics on pilot analog

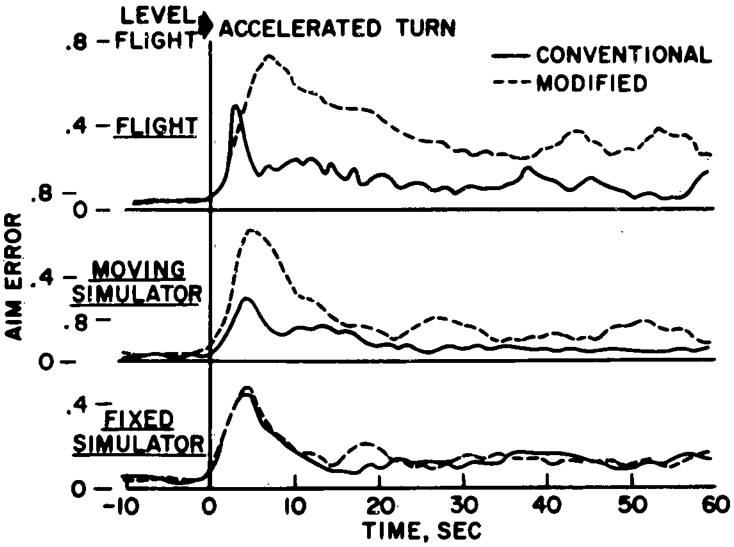

Fig. 21 Attitude instrument presentation

DISCUSSION

R.J. Balmer (U.K.): We have been looking into the use of simulators for VTOL aircraft, particularly for simulation of flight under visual conditions. We have come across a system of presenting a visual display to the pilot using a television display in which a T.V. camera moves relative to a model of the ground, the motion of the camera corresponding to the motion of the simulated aircraft. We have only had a brief look at this system, but have seen enough to believe it to be very promising. Both technicians and pilots found the display, which represented low-altitude flight over an airfield, to be very realistic - particularly as regards the impression one received of linear and angular velocities and perspective effects. I believe such a system has been used by one firm in the U.S.

Would Mr. Rathert like to comment on such a system?

Author's reply: The Ames Research Center of the N.A.S.A. is in the final stages of installing a commercial (Dalto Corporation) simulator of this type which includes a complete conventional landing presentation.. We are not in a position to comment on the device until we have operated it, although obviously the subjective impressions of our test pilots during demonstrations was sufficiently favorable to lead us to buy one. We have not used such a device in the V/STOL mission at all.

D. Lean (U.K.): How is the effect of size of aircraft to be simulated in relation, for example, to deviation levels of control power and response during approach and landing?

Author's reply: If the question is understood correctly, the control power and response and the vehicle response including the effects of inertia are computed accurately on the analog computer that closes the loop around the pilot in the simulator. If the question relates to intangibles such as fear of striking the ground with a wing tip due to the low control power and high inertia, we can only stress that the pilot must be given frequent opportunity to make direct comparisons between flight and the simulator with flight vehicles as close to the size of those being studied as practicable.

H.H.B.M. Thomas (U.K.): In analysis using a transfer function to represent a pilot, difficulty arises in defining the cues which he uses to perform different tasks.

Has there been any attempt to get this information from simulators of differing degree of representation?

Author's reply: We have run a number of tests in which the identical task was performed on a series of simulators providing cumulative numbers and types of cues. These data are mostly for one piloting task (compensatory tracking) and they have not been explicitly analyzed to relate the cues and the tasks. These data are in References 1, 9, 11, 13 and 14 of the written paper. Incidentally, References 12 and 13 summarize our experience to date in working with the human pilot transfer function.

F.A. Gaynor (U.S.A.): Would Mr. Rathert please clarify Figure 21? Attitude Instrument Presentation? In particular, he indicated that the conventional and modified display results in the moving simulator should be interpreted or approached with caution.

Author's reply: These results are discussed in Reference 14 of my text in more detail than is possible here. Figure 21 compares continuous time-histories of aim error in gunnery runs made with two different types of bank-angle display and for two types of simulator in addition to actual flight. The principal point to be made from the figure is that neither type of simulator showed nearly as much difference between the two displays as was revealed by actual flight tests in manoeuvering conditions. The reason for my 'approached with caution' statement is that we simply do not fully understand the physiological effects involved and therefore cannot extrapolate from any simulators with confidence when assessing instrument displays for manoeuvering flight. For those familiar with the terminology the conventional display is sometimes referred to as 'inside-out' and the modified as 'outside-in', the 'inside-out' display of course corresponding to the almost universal artificial gyro-horizon instrument.

ADDENDUM

AGARD SPECIALISTS' MEETING

on

STABILITY AND CONTROL

Complete List of Papers Presented

Following is a list of the titles and authors of the 41 papers presented at the Stability and Control Meeting held in Brussels in April, 1960, together with the AGARD Report number covering the publication of each paper.

INTRODUCTORY PAPERS

The Aeroplane Designer's Approach to Stability and Control, by G.H.Lee (United Kingdom)	Report 334
The Missile Designer's Approach to Stability and Control Problems, by M.W.Hunter and J.W.Hindes (United States)	Report 335

DESIGN REQUIREMENTS

Flying Qualities Requirements for United States Navy and Air Force Aircraft, by W.Koven and R.Wasicko (United States)	Report 336
Design Aims for Stability and Control of Piloted Aircraft, by H.J.Allwright (United Kingdom)	Report 337
Design Criteria for Missiles, by L.G.Evans (United Kingdom) ..	Report 338

AERODYNAMIC DERIVATIVES

State of the Art of Estimation of Derivatives, by H.H.B.M.Thomas (United Kingdom)	Report 339
The Estimation of Oscillatory Wing and Control Derivatives, by W.E.A.Acum and H.C.Garner (United Kingdom)	Report 340
Current Progress in the Estimation of Stability Derivatives, by L.V.Malthan and D E.Hoak (United States)	Report 341
Calculation of Non-Linear Aerodynamic Stability Derivatives of Aeroplanes, by K.Gersten (Germany)	Report 342

AEROELASTIC EFFECTS

COUPLING PHENOMENA

STABILITY AND CONTROL AT HIGH LIFT

THE APPLICATION OF SERVO-MECHANISMS

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AGL (1) 6-62-1M-89640

AGARD Report 365
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development.
THE USE OF PILOTED FLIGHT SIMULATORS IN GENERAL RESEARCH
George A. Rathert, Jr., Brent Y. Creer and Melvin Sadoff
1961
19 pages, incl. 14 refs., 21 figs; plus discussion and bibliography of papers presented at the Stability and Control Meeting

Recent research on a number of general flying-qualities problems is reviewed in order to discuss the use of piloted simulators and their validity. Direct comparisons between different types of simulators and actual flight tests are used to show which information cues to the pilot are required

P.T.O.

629.13.014.7

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