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A Simulation Evaluation of the Engine Monitoring and Control System Display

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National Aeronautics and
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Summary

The Engine Monitoring and Control System (E-MACS) display described in this paper is a proof-of-concept product of a design philosophy that is focused toward providing information that is more directly oriented to the user's task than traditionally designed displays. The E-MACS display is a new concept for an engine instrument display, the purpose of which is to provide an enhanced means for a pilot to control and monitor engine performance. It provides graphically presented information about performance capabilities, current performance, and engine component or subsystem operational conditions relative to nominal conditions. The concept was evaluated against a traditional, state-of-the-art, electronic engine display format. Sixteen pilots participated in this evaluation. The results of this evaluation showed a substantial pilot preference for the E-MACS display relative to the traditional display. The results of the failure-detection portion of the evaluation (what is typically termed "operator error") showed a 100-percent detection rate for the E-MACS display relative to a 57-percent rate for the traditional display. From these results, it is concluded that by providing this type of information in the cockpit, a reduction in pilot work load and an enhanced ability for detecting degraded or off-nominal conditions is probable, thus leading to an increase in operational safety.

Introduction

At present, engine system instruments typically provide data that are based solely on the single sensor to which they are connected. Modern, electronically generated displays of current and planned aircraft follow this same approach, with multiple instruments portrayed on a single electronic display. That is, the forms of several traditional (mechanical) instruments are now represented on a single electronic display.

With these current engine displays, the pilot uses either engine pressure ratio (EPR) or low-pressure compressor rotational speed (N_1) to control engine power. For the engine of this study, EPR is the primary engine control parameter. In addition, N_1 and exhaust gas temperature (EGT) parameters must also be used during high-power operations to prevent over-limit conditions. To monitor the engine subsystem parameters (e.g., oil pressure, oil temperature, fuel flow, etc.) for proper operation, current displays customarily provide information via fixed-scale and moving-pointer indicators (typically dial or moving-column indicators). The range for an indicator (i.e., where the indicator begins and ends) is generally the range that may be physically possible for that subsystem. To make out-of-limit conditions more noticeable to the pilot, operating limits are usually represented by fixed, color-coded markers on these indicators. To determine an out-of-limit condition, then, the position of each pointer of each indicator must be compared with its respective operating-limits markers. This may seem to be a trivial task until one realizes that five or more indicators are usually needed for each engine. Additionally, these displays do not provide any direct means for determining when a subsystem is degrading but still within limits. Pilots must rely either on tables and charts (when and if they are available) or on experience to detect degraded operation.

A potential problem with these current displays is that raw sensor data may not be the best information to provide to the pilot. This type of data may contribute to pilot work load and associated pilot errors. Years ago, no other choice was available. Today, however, with the vast proliferation of microprocessor technology in the aircraft cockpit, this is no longer the case. We can now process raw sensor data into information that is more oriented toward the task that the pilot is required to perform and present it in a manner that is easier to understand and use.

The Engine Monitoring and Control System (E-MACS) display described in this paper is a proof-of-concept product of a design philosophy (ref. 1) that is focused toward providing information that is more oriented to the user's task than traditionally designed displays. By providing information in a form that is more directly aligned with the user's task, a reduction of the cognitive work load associated with the use of displayed information may be possible. To provide this information, it may be required that the raw data that are typically displayed be processed into a more appropriate representation and presented in a manner that permits easier assimilation. The underlying premise to this design philosophy is that the computational capabilities of modern, graphics-based display systems should be considered in the display design process.

The E-MACS display was designed to provide information that is not presently available to the pilot regarding total engine performance and to present this information in a simple and more easily used form. This information was based on a simplified, functional model of the monitored engines within the E-MACS system. This functional model provided data on how the "ideal" engine would be performing under the current operating conditions. The purpose of the E-MACS, then, is to provide an enhanced means for a pilot to control and monitor engine performance. It provides graphically presented information about performance capabilities, current performance, and engine component or subsystem operational conditions relative to nominal conditions.

To validate this design, the E-MACS display was evaluated against a modern, state-of-the-art, electronic engine display format. The evaluation was conducted in a fixed-based simulator with 16 pilots participating in the test. A description of the E-MACS display design, the test conditions, and the test results is provided in the succeeding sections.

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Nomenclature

Abbreviations

CAS	calibrated airspeed
CRT	cathode ray tube
EGT	exhaust gas temperature
EPR	engine pressure ratio
FF	fuel flow
L, R	left and right, respectively
MAT	maximum available thrust
N_1, N1	low-pressure engine compressor rotational speed
N_2, N2	high-pressure engine compressor rotational speed
PRES, PRESS	pressure
QTY	quantity
TEMP	temperature
V_1	decision speed, maximum speed to abort a takeoff

Definitions

advanced format	engine display format designed for this study (E-MACS)
caution limit	component operation in this region is time limited
degraded condition	condition where a component or system is not operating properly but is within its normal operating limits
modern format	current technology, state-of-the-art, engine display format
out-of-tolerance condition	condition where a component or system is not operating within its normal operating limits
warning limit	component operation in this region may result in failure

Baseline Display

For this study, a traditional, state-of-the-art electronic engine display was used as a basis of comparison. The display chosen for this baseline was modeled after the Engine Indication and Crew Alerting System (EICAS) in the Boeing 757 and 767 aircraft families (refs. 2 to 4). The EICAS display is based on contemporary design practices and has proven to be superior to the conventional electromechanical instruments that it replaced (ref. 5). For this study, it should be noted that no caution or alerting system, except what was provided by the display, was used. It should also be noted that since current caution and alerting systems do not detect degraded conditions, the ability to detect a degraded condition using a traditional display is based largely on a pilot's experience. The implementation of this display was tailored for the aircraft engines used in this study.

A brief examination of this baseline display will begin with a description of the display elements. The most significant information parameter for this display involves data relating to EPR. On a cursory inspection of figure 1, which shows the display element for EPR, it would appear that little more than EPR sensor data were being presented via a conventional analog display element, a circular dial. This display element was, in fact, a combination of several display elements and possessed some unusual features.

The first parameter to note is the EPR reference, which was presented both as a digital value and as a reference pointer on the dial circumference. Similarly, the actual EPR value was presented digitally and by the pointer on the dial. The digital presentation could provide the pilot with a precise indication of the EPR value, whereas the dial and pointer provided the pilot with a means of estimating and predicting the EPR value during dynamic conditions. Since a precise EPR value was provided via the digital element, scale markings were not deemed necessary on the EPR dial. This aided in visually decluttering the display.

In addition to the movement of the EPR pointer, an alternative means for estimating EPR was provided by the EPR predictor arc. The arc appeared on the display whenever the actual EPR value and the commanded EPR value were not the same. This arc spanned across a region beginning at the current EPR value, at the end of the EPR pointer, and terminated at a position relative to an EPR value that the fuel control (based on throttle position) was attempting to obtain. (This was not the same value as the EPR reference.) It should be noted that the EPR was the primary indicator of engine power and that numerous and large changes of the EPR are typical during normal flight operations. Additionally, a lag or delay of 5 to 10 sec in engine response to a pilot control input is not unusual when going from an idle to a high-power condition. Therefore, the ability to accurately estimate or predict EPR reduces the required attention by the pilot during power changes.

Similar to the EPR predictor, the EPR warning limit was a continuously computed maximum limit based on current ambient conditions. This limit was shown by a red "range marker" (or "marking") on the EPR dial. The range marker spanned the region from the warning limit to an EPR value of 2.5. The EPR caution limit, shown by a yellow range marker on the EPR dial, was a computed maximum-continuous EPR limit based on current ambient conditions. If the takeoff and maximum-continuous EPR limits were the same, no caution limit was shown. The range marker spanned the region from the caution limit to the warning limit. The computation of both limits by the system alleviated the pilot from this duty.

An additional cue was provided to the pilot whenever the EPR was within either the warning region or the caution region. The digital EPR value was usually presented in a white color. During operation in the caution region, the digital readout was displayed in yellow; during operation in the warning region, the digital readout was displayed in red.

The display element for EPR, then, furnished EPR reference information through a digital display element (which provided an exact display of the EPR reference) and a reference pointer (which was used with the actual EPR pointer). EPR trend information was provided implicitly by the motion of the actual EPR pointer and explicitly by an EPR predictor arc symbol. Precise EPR information was provided by a digital display element that could be used with the digital element for EPR reference to determine if the engine power was set correctly. Operating ranges were dynamically provided. Alert cuing was provided by color coding the digital element for actual EPR. The total integration of these features resulted in a fairly sophisticated and easy-to-use display of EPR information.

The dial portion of the display elements for N_1, N_2, EGT, and fuel flow was similar to that for EPR, with the ranges appropriate for the particular parameter. As with EPR, a digital display element for the actual value of the parameter was provided. Warning and caution range markings (fixed values) were provided for N_1, N_2, and EGT. Like the EPR display element, the color of the digital element corresponded to the operating region of the parameter. An example illustration, using the N_1 parameter, is given in figure 2.

Because of their generally stable characteristics, the oil system parameters were presented in a slightly different manner. Each of these parameters was presented by a combination of a linear scale with a moving pointer and a digital display element. The linear scale was partitioned into the appropriate normal, caution, and warning regions for the parameter. The presentation of this information using linear-scale display elements reduced the physical display area compared with that of a circular-dial approach. This was a reasonable design choice because of the stable nature of these parameters. The digital element was mechanized in a manner similar to that for the circular-dial display elements. An example illustration, using the oil pressure parameter, is given in figure 3.

The individual display elements were grouped or arranged primarily by criticality and, then, by frequency of use. The arrangement was in a top-to-bottom, left-to-right order. Additionally, since the general application was for a two-engine aircraft, two sets of display elements were used in this design. A functional grouping, which places the display elements together by function, was also used in this design. For example, the EPR display elements for both engines were grouped together; the EPR element for the left engine was placed physically to the left of the EPR element for the right engine. An advantage of this arrangement was that, because both engines are typically set to produce equivalent amounts of power, similar parameters should operate with relatively similar values with respect to one another. By being able to compare similar parameters, some of the uncertainty that the pilot may experience in determining proper component operation may be reduced.

The overall integration of these display elements into the traditional baseline display is shown in figures 4 and 5. The display was physically presented on two CRT's in a left-to-right arrangement. This particular left-to-right arrangement was a constraint imposed by the cockpit layout that was used in the experimental evaluation phase of this study. The original EICAS arrangement was slightly modified to conform to this layout. The modification involved shifting the entire left display toward the right side of the CRT. This shifting provided for a reduced visual scan area. The actual EICAS implementation in the Boeing 757 and 767 aircraft families was provided by two CRT's in a top-to-bottom arrangement.

E-MACS Display

Design Concept

The most significant step in this design was to understand the task that the human must perform. For this application, the global task for the pilot was (1) to control engine power through the use of a manual controller and an appropriate display element and (2) to monitor other engine system parameters to ascertain whether these parameters are within acceptable limits. Therefore, in determining the information required for an aircraft engine display, the information requirements were separated into the information required for control and the information required for systems monitoring. For the engine used in this study, the conventional display element used for control is an EPR gauge, and the pilot is expected to derive power settings from this pressure measurement. In addition, N_1 and EGT parameters must also be used during high-power operations to prevent over-limit conditions. The design assumption for the E-MACS display was that the pilot should not be controlling EPR, N_1, or EGT. Instead, the pilot should be controlling engine thrust, which is based on EPR, N_1, and EGT, with the form of the display supporting this data representation. For the control task, then, E-MACS uses a display element based on a model of engine thrust.

For the systems monitoring task, system parameters (typically oil pressure, oil temperature, and fuel flow) are usually displayed via fixed-scale and moving-pointer indicators (as described in the "Baseline Display" section above). The visible parameter range for an indicator is generally the range that is physically possible for that system. Additionally, operating limits are usually represented by fixed, color-coded markers on these indicators. For a monitoring task, then, the position of each pointer of each indicator must be compared with its respective operating-limits markers. Some attempt is usually made to reduce the complexity of this comparison task by orienting or scaling these indicators so that all the pointers of these display elements are roughly aligned during normal operational conditions. For the monitoring task, the emphasis for the E-MACS implementation was on presenting quantitative information in a form that may be cognitively processed in a qualitative manner, thereby reducing the pilot's mental work load.

The display element used by the E-MACS display for the monitoring task was a deviation column indicator. This display element has been shown to allow for holistic visual processing or pattern recognition (refs. 6 and 7). The range of this indicator was equally divided into normal, caution, and warning subranges for both above and below nominal operation conditions. Typically, this indicator would show for each engine parameter the difference between the value of the actual subsystem sensor and the nominal value from the model. In addition, conventional subsystem limitations were merged with the deviations as the parameter approaches its respective limits, thus assuring that conventional limitations are displayed. Because this indicator presented the difference between actual and nominal (or limit) conditions, the size of the column was a direct indication of the severity of the problem. Additionally, previous published studies have shown that deviation column indicators, in general, provide a faster means for presenting multiple-element data (refs. 6 and 7). This indicator should allow the pilot to determine the status of all engine subsystems at a single glance.

Specific Application

The primary implementation requirement for the E-MACS display was the generation of the estimated value for each of the engine parameters for a Pratt & Whitney JT8D-7 turbofan engine. In order to provide most of these estimates, a third-order polynomial equation for each parameter was used. (Fixed values were used for the oil system parameters.) The coefficients for these polynomials were obtained from a regression analysis performed on a data set taken from the simulated engine. Further implementation details are provided in reference 8.

The general form for the display elements used in the E-MACS display was a fixed-scales/moving-columns form. The display elements themselves may be separated into two distinct cases: control and monitoring.

Control. The display elements for engine control were the thrust indicators (see fig. 6) scaled from −10 to 110 percent, with 100 percent defined as the maximum available thrust without exceeding any engine limit. This maximum available thrust (MAT) was a value computed from a simplified engine model. This value was shown, in pounds, at the top of each thrust indicator. In addition, the following elements were part of the thrust indicators:

1. Thrust warning limit: The thrust warning limit, which was the MAT and was shown by a red range marker on the thrust scale, always began at 100 percent. Under normal operations, no other engine parameter (N_1, N_2, or EGT) would be within a warning area unless the current thrust value was in the warning area.
2. Thrust caution limit: The thrust caution limit, shown by a yellow range marker on the thrust scale, was based on a computed maximum-continuous thrust. Under normal operations, no other engine parameter (N_1, N_2, or EGT) would be within a caution area unless the current thrust value was in the caution area.
3. Thrust reference pointer: For the takeoff conditions, a thrust reference pointer would be displayed on each thrust indicator. The reference value itself, in percent of the MAT, would be digitally presented for a 5-sec period immediately following a change in the reference value.
4. Thrust predictor: The engine model, independent of the engine, computed an estimate of the commanded thrust based on current conditions. This estimate was presented both as a predictor column and as a predictor pointer. The predictor pointer included a digital readout, in percent of the MAT, of the predicted thrust.
5. Current thrust: The current thrust, normalized by the MAT value, was displayed as a column on the thrust indicator. The color of the column would reflect the operating condition (green for normal, yellow for caution, and red for warning). Under steady-state situations, the thrust predictor and the current thrust value should be in general agreement.

The design advantages of this approach were as follows: First, the position on the indicators for maximum allowable power always remained the same. This provided the pilot with a fixed, visual reference location, thereby reducing visual scanning. Second, by using a scale normalized by the maximum allowable power for the current conditions (air temperature, pressure altitude, and Mach number), the takeoff power setting charts were no longer required. The takeoff power setting using this concept, in percent of the MAT, remained a constant. Finally, the thrust predictor, which was based on a simplified mathematical model of the engine, provided an independent check between commanded and actual engine power.

Monitoring. The major display element used for monitoring was a deviation column indicator. (See fig. 7.) In general, this indicator would show a difference between the actual value and an estimated, ideal value (provided by the engine model) for each engine parameter. Because this indicator presented the difference between actual and ideal (or limit) conditions, the size of the column was a direct indication of the severity of the problem. Also, this type of display element allows for holistic processing (pattern recognition) by the human. That is, the reaction time for the detection of abnormal system status does not increase as the number of parameters is increased (ref. 6). The estimated value was produced by the simplified engine model. The indicator itself was divided into normal, caution, and warning ranges for differences both above and below the estimate.

Under nominal operating conditions, then, the height of a column usually showed the deviation or difference from the ideal value for that parameter. However, conventional operating limitations should also be considered whenever any parameter approaches a limit. That is, under very high thrust conditions, the N_1 may be operating in the conventional caution region (94 to 100.1 percent for this engine). If the engine is operating properly under these conditions, the actual N_1 value and the ideal N_1 value (from the model) would be roughly equal. Therefore, little or no deviation would exist. However, the pilot needs to be aware that the N_1 is operating in the conventional caution region. To provide this awareness, a limitation value was integrated with the deviation value whenever a parameter approached any operating limit. For example, the limitation value for the N_1 caution, where the N_1 caution began at 94-percent N_1, became active when the N_1 value reached or exceeded 89-percent N_1. The design of this limitation value was such that the column representing N_1 would just begin transitioning into the caution area as the N_1 value reached 94 percent. The deviation columns were displayed in the color of the associated range.

Each deviation column element included a digital presentation of the actual value. This digital readout was displayed in the same color as the associated column.

The overall integration of these display elements into the completed E-MACS display is shown in figures 8 and 9. This integration or grouping of display elements was based on the layout of the baseline display. The comparable grouping of display elements in the E-MACS display was done to alleviate this grouping effect in the evaluation. As with the traditional display, the E-MACS display was physically presented on two CRT's in a left-to-right arrangement. This particular left-to-right arrangement was again a constraint imposed by the simulator cockpit.

Test Conditions

Aircraft Simulator

The aircraft simulator used for this evaluation was a fixed-base cockpit configured as the research cockpit of the NASA Transport Systems Research Vehicle (TSRV) airplane (ref. 8). This simulation included a six-degree-of-freedom set of nonlinear equations of motion and functionally represented the aspects of the advanced flight control configuration of the airplane. The engine model included in this simulation was a nonlinear, engineering model of a Pratt & Whitney JT8D-7 turbofan engine.

Six electronic CRT displays were provided in the cockpit. Primary and navigation displays (refs. 8 to 12) were provided in the form of an over-and-under arrangement for vehicle control and guidance, two on each side of the cockpit. Two side-by-side, center-mounted CRT displays were provided for systems management. These latter CRT's were used to present the engine displays relevant to this study. All CRT displays were approximately 9 in. diagonal in size. These displays were generated on an Adage AGT 340 graphics computer. The engine displays were stroke drawings using four colors. Raster features were synthesized by stroke-filling. The cockpit arrangement of these CRT displays can be seen in figure 10.

Evaluation Conditions

For this evaluation, the traditional, state-of-the-art display was designated as the modern display and was used as a basis for comparison. The general form and function of this display is familiar to the commercial aircraft piloting community.

For the evaluation of these displays, 16 pilots were used, and all were qualified in multiengine jet airplanes. Five of the subjects were NASA test pilots, 1 subject was a pilot for a commercial air carrier, and the remaining 10 subjects were U.S. Air Force operational pilots. Each subject was briefed prior to the simulation test with respect to the displays, the aircraft cockpit systems, and the evaluation tasks. Each briefing began with the subject reading a formal pilot-briefing handout (appendix A). This reading was followed by the subject taking a written quiz (appendix B) on the critical engine parameters for the aircraft engine used in this study. The primary intent of this quiz was to assure that the subjects were familiar with the operating limitations of this engine. Each subject was then provided with an informal 1½-hour briefing on the simulator and on both sets of engine displays.

The simulator evaluation began after the pilot briefing. The evaluation sequence was as follows:

1. Simulator familiarization and initial subjective evaluation of the modern display. This subjective evaluation required the completion of a written questionnaire (questionnaire A shown in appendix C) specifically appraising the modern display. (This required approximately 1 hour.)
2. Simulator familiarization and initial subjective evaluation of the E-MACS display. As part of this evaluation, the completion of a written questionnaire specifically appraising the E-MACS display was required (questionnaire B shown in appendix C). Following this evaluation, a second questionnaire was administered (questionnaire C shown in appendix C) which required the subject to comparatively rate the two displays. (This required approximately 1 hour.)
3. Practice and quantitative evaluation of one of the two engine displays. (This required approximately 15 minutes.)
4. Practice and quantitative evaluation of the other engine display. (This required approximately 15 minutes.)
5. Complete a final subjective questionnaire set. The comparative questionnaire (questionnaire C shown in appendix C) was again administered. Following this, the subject was then requested to provide written comments regarding the E-MACS display only (questionnaire D shown in appendix C).

Because no demands were placed on the subjects that were specific to the simulated aircraft, the simulator familiarization and subjective evaluations were performed concurrently. Additionally, because all the subjects were generally familiar with the modern display, all subjective evaluations began with this display.

For the initial, subjective evaluation of each display, the subjects were provided with flight scenarios that included normal, degraded, and out-of-tolerance engine systems conditions. The majority of the scenarios involved a takeoff task since this task is generally the most engine-system critical. The takeoff conditions included a wide range of aircraft weights and airport elevations. These two factors significantly affect the acceleration potential of the aircraft and, therefore, significantly affect takeoff capabilities. For these scenarios, the reference EPR or thrust was automatically set for the pilot. The other scenarios were in-flight, cruise situations. It should be noted again that no caution or alerting system was used, except what was provided by the displays. A list of these scenarios is provided in table I.

For the initial evaluations, the subjects were allowed to stop or "freeze" the simulator at any time to analyze a situation. Any situation or condition could be discussed with the test engineer. The subjects were always advised of any degraded or failure (out-of-tolerance) condition. As previously stated, they were required to rate each display on its suitability at the end of each of these two evaluation phases (questionnaires A and B). Additionally, the subjects were required to comparatively evaluate the displays at the end of the second evaluation (questionnaire C).

Following the initial subjective evaluations, a quantitative evaluation was performed for each of the two displays. During this part of the overall evaluation, one-half of the subjects began with the modern display and the other one-half began with the E-MACS display. For each display, the subjects were required to perform two takeoff and two in-flight tasks. The subjects were advised that system failure scenarios would be randomly included in these tasks. In actuality, the order of the failure scenarios was random, but one failure scenario and one non-failure scenario were included in each task pair (takeoff and in-flight). No scenarios were repeated for any subject.

The scenarios used for this portion of the evaluation were similar to those used earlier with the following noteworthy exception: the displays were shown only for set periods of time. Except for those set time periods, the CRT displays were electronically blanked. Switching the displays on and off was done to reduce the tendency of the subjects to give excessive emphasis to the engine control and monitoring tasks. That is, the engine control and monitoring tasks are not the pilot's primary tasks during actual, operational situations. If the airplane takeoff task is considered the pilot's primary task, during which engine control and performance are critical, it may be observed that the time devoted to engine control and monitoring is fairly small compared with the overall task. Since engine monitoring and control was the primary task for this portion of the test, this was the pilot's only task. No other cockpit duties were performed.

To determine an appropriate time period for the viewing of the engine displays, a preliminary test was conducted several months prior to this evaluation. For this preliminary test, 3 subjects (none of the 16 used for this evaluation) were each provided with takeoff and in-flight scenarios similar to those used in the actual evaluation. The intent of this test was to determine when the subject viewed the engine displays during the performance of an overall flight task (whether during a takeoff task or an in-flight task requiring an increase in power). The subjects were not advised as to the intent of this preliminary test. A record of the subjects' viewing periods of

Table I. Scenarios for Familiarization and the Subjective Evaluations

(a) Scenario matrix

Scenario	Condition	Altitude, ft	CAS, knots	Weight, lb	Fault number
F1	Takeoff	0	0	80 000	
F2	↓	↓	↓	↓	1
F3	↓	↓	↓	↓	4
F4	↓	↓	↓	↓	2
F5	↓	↓	↓	↓	5
F6	↓	↓	↓	112 000	
F7	↓	5 333	↓	80 000	
F8	↓	5 333	↓	102 000	
F9	Cruise	18 000	290	91 000	
F10	Cruise	18 000	290	91 000	3
F11	Cruise	18 000	290	91 000	4

(b) Fault number key for table I(a)

Fault number	Description
–	No fault, normal operation
1	Low oil pressure on left engine. Problem is a function of N_2, with oil pressure decreasing from normal into caution area above 60 percent N_2.
2	Oil leak, both engines. Problem begins after 45 sec of operation. Potential outcome is total loss of oil from system.
3	Oil leak on left engine. Problem develops from normal to 0 quantity over 90-sec period. Potential outcome is total loss of oil from system.
4	High EGT for both engines. Problem is that both engines are operating 100°C hotter than normal, with potential result of an engine over-temperature condition.
5	Low oil pressure on both engines with left engine decreasing faster. Problem is function of time, with left-engine oil pressure decreasing from normal into caution area with 1 sec.

the engine displays was kept. The resulting average viewing periods from this preliminary test were then used during this later evaluation of the displays. For the takeoff scenarios, this resulted in a 4-sec period following the initial throttle advance, a 2-sec period beginning at 55 knots (for the 60-knot power check), and a 2-sec period beginning 5 knots prior to V_1. For the takeoff scenarios, the displays were initially on. For the in-flight scenarios, the displays were initially off and a single 3-sec on-period was used.

To reduce the effect of subject inattention to the engine control and monitoring tasks during these quantitative evaluations, the subjects were not allowed to perform any other flight task (e.g., the control of the aircraft flight path). Additionally, the test engineer provided all aircraft speed callouts (55 knots and 5 knots prior to V_1). During the evaluation, the subjects were advised that if an engine problem developed, the task was to be immediately terminated and the failure reported. The subjects were not informed of the nature of a failure for these scenarios either before, during, or after the test. The scenarios for this part of the evaluation and their order of use are given in tables II and III, respectively.

Following the quantitative evaluations, the subjects were again required to comparatively rate the displays (questionnaire C for the second time). A final questionnaire was then administered where the subjects were required to provide brief comments pertaining to the attributes of the E-MACS display.

The product of this evaluation was a set of test data from each subject that included the following: questionnaire results individually rating each display (questionnaires A and B); questionnaire results from two comparative questionnaires (questionnaire C), one administered prior to the quantitative test and one administered afterward; quantitative results from eight no-failure scenarios and eight failure scenarios; and a set of general comments.

Evaluation Results

Qualitative Results

In analyzing the test data, differences in the results of the qualitative data obtained from the initial subjective evaluations (questionnaires A and B) were deemed experimentally significant only if the difference in mean values for relevant questions on the questionnaires was greater than 20 percent. (The ratings were on a scale of 1 to 5, with 1 being the most favorable and 5 being the least favorable. The 20-percent value, which was chosen prior to the data analysis as a level for practical significance, was equivalent to one block on the questionnaire response.) For example, the difference between the average response to question 1 of questionnaire A and question 1 of questionnaire B had to exceed 20 percent for one response to be considered better than the other. Similarly, the results of the comparative evaluations (questionnaire C) were deemed experimentally significant only if the average rating was at least 20 percent to the left or right (favoring the modern or E-MACS display) of the center, "no difference" rating.

Table II. Scenarios for the Quantitative Evaluation

(a) Scenario matrix

Scenario	Condition	Altitude, ft	CAS, knots	Weight, lb	Fault number
1	Takeoff	0	0	108 000	
2	↓	0	0	85 000	1
3		4 900	0	108 000	
4		4 900	0	85 000	2
5	Cruise	16 000	270	↓	
6	↓	↓	270		4
7			300		
8			300		3

(b) Fault number key for table II(a)

Fault number	Description
–	No fault, normal operation
1	EPR sensor error, high EPR values for both engines. Simulation of a blocked pressure probe leading to higher than true EPR readings above 1.0 EPR. Potential result is insufficient power for the flight condition.
2	High oil temperature on left engine. Problem is a function of N_2, with oil temperature increasing from normal into caution area above 60 percent N_2.
3	High N_2 speeds on both engines. Problem is that N_2 is increasing higher than normal, with potential result of an N_2 overspeed condition.
4	High EGT for both engines. Problem is that both engines are operating hotter than normal (75°C and 83°C for the left and right engines, respectively), with potential result of an engine over-temperature condition.

The responses to questionnaires A and B for questions 1 to 6 are shown graphically in figures 11 to 16, respectively. No significant differences between the responses were obtained for the first four questions. The last two questions (the questions pertaining to the monitoring task) showed a more favorable rating of the E-MACS display. For questions 5 and 6, average ratings of 1.2 and 1.3, respectively, for the E-MACS display were obtained versus average ratings of 3.9 and 2.9 for the modern display.

Table III. Scenario Sequence for the Quantitative Evaluation

Sequence	Scenario numbers for pilots—															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Modern format								E-MACS format							
1	1	4	4	2	3	1	2	3	4	4	3	3	2	1	1	2
2	2	1	3	1	4	2	3	4	1	3	2	4	1	4	2	3
3	6	7	8	8	5	6	5	7	6	7	6	5	8	5	7	8
4	5	6	7	5	6	7	8	8	5	8	5	8	7	6	6	7
	E-MACS format								Modern format							
5	3	3	2	4	1	4	1	2	3	1	1	2	4	2	3	4
6	4	2	1	3	2	3	4	1	2	2	4	1	3	3	4	1
7	8	5	6	7	7	8	6	5	8	5	7	7	6	8	5	6
8	7	8	5	6	8	5	7	6	7	6	8	6	5	7	8	5

The comparative questionnaire was administered twice, once just prior to the quantitative evaluation (the timed test) and once immediately after this test. Examining the responses to the questionnaires administered prior to the quantitative evaluation showed a preference for the E-MACS display. A general preference (question 1) with regard to ease of use was observed for this display with an average rating of 4.2 on a scale of 1 to 5, where a rating of 1 was defined as a total preference for the modern display and a rating of 5 was defined as a total preference for the E-MACS display. Preferences were also shown for the E-MACS display regarding the monitoring task (questions 5 and 6) with ratings of 4.4 and 4.5, respectively.

An interesting trend was noted from the responses to questionnaire C administered after the quantitative evaluation. Preferences were again shown for the E-MACS display, but there was a more favorable rating in all these cases (all questions). All the responses were experimentally significant with ratings of 4.7, 4.4, 4.2, 4.3, 4.8, and 4.9 for questions 1 to 6, respectively. (These results are shown graphically in figs. 17 to 22.) It is assumed that forcing the subjects into time-critical situations, as was done for the quantitative evaluations, caused this rating change. This was especially true for the monitoring portion of the display where the ability to perform the monitoring task (questions 5 and 6) was rated 4.8 and 4.9, respectively, on a scale of 5. The overall comments from questionnaire D showed a very favorable response to the E-MACS display, with special emphasis on the monitoring capabilities provided by this format.

Quantitative Results

The analysis of the quantitative data substantiated the qualitative results. During the quantitative testing, a total of 32 degraded or out-of-tolerance conditions were presented for each display. When the subjects were using the E-MACS display, all 32 failure cases were detected. With the modern display, 14 failure cases were not detected; 4 of these cases were out-of-tolerance conditions and the remaining 10 were degraded conditions. (A summary is provided in table IV.) The differences in the overall detection of failures, the detection of degraded conditions, and the detection of out-of-tolerance conditions between the two displays were statistically significant at the 95-percent confidence level (where the hypothesis that there was no difference between the displays yielded chi-square (χ^2) values of 17.92, 14.55, and 4.57, respectively, with $\chi^2_{0.05;1} = 3.84$).

Table IV. Undetected Faults

Type of format	Number of degraded faults	Number of out-of-tolerance faults	Percent of total faults
Modern	10	4	43
E-MACS	0	0	0

It should be noted that the ability to detect a degraded condition using a traditional display is based largely on a pilot's recent experience in that aircraft under similar operating situations. (It is also noteworthy that caution and alerting systems do not detect degraded conditions.) That is, the pilot must recall from memory what the value for a parameter should be for a given operating condition. The pilot then compares this recalled value with the actual, current value to determine if a parameter (and the related system) is correct. Because of this, the inability to detect degraded conditions using the modern display was not unexpected. It is also noteworthy that of the 10 degraded conditions that were not detected with the modern display, 8 of these conditions involved an abnormally high EPR or thrust reading (failure condition 1). This particular degradation, modeled after a recent commercial aircraft accident (ref. 13), was never detected when the modern display was used.

Overall Results

The overall results of this evaluation showed a favorable increase in both the user's subjective assessment and failure detection rate (and therefore a reduction in what is typically termed "operator error") for the E-MACS display relative to the traditional (modern) display. These results confirm the premise that providing information tailored to the user's task, both in content and form, increases the user's ability to utilize that information.

Conclusions

A ground-based aircraft simulation study was conducted to evaluate a new concept for aircraft engine displays. This display concept is based on a design philosophy that is focused toward providing information that is more oriented to the user's task than traditionally designed displays. The product of this design was the Engine Monitoring And Control System (E-MACS) display. The results of this evaluation are given as follows:

1. A favorable increase was shown for both the pilots' subjective assessments and failure detection rates (and therefore a reduction in what is typically termed "operator error") for the E-MACS display relative to a traditional, state-of-the-art display.

2. With the traditional, state-of-the-art display, 43 percent of all engine faults introduced during this evaluation were undetected; however, with the E-MACS display, no faults were undetected.

3. Of the 43-percent undetected faults with the traditional display, 31 percent of these faults were system degradations (a condition where a component or system is not operating properly but is within its normal operating limits). It should be noted that since current caution and alerting systems do not detect degraded conditions, the ability to detect a degraded condition using a traditional display is based largely on a pilot's recent experience in that aircraft under similar operating situations.

From these results, it is concluded that by providing this type of information in the cockpit, a reduction in pilot work load and an enhanced ability for detecting degraded or off-nominal conditions are probable, thus leading to an increase in operational safety.

NASA Langley Research Center
Hampton, VA 23665-5225
November 29, 1989

Appendix A

Pilot-Briefing Handout

Purpose

The purpose of this evaluation is to compare a modern engine display format, somewhat like the Boeing 757/767, against an advanced display format. This evaluation will use a part-task, real-time simulation. Both takeoff and inflight scenarios will be used. For the takeoff scenarios, the piloting task will be an acceleration, initiated from 0 speed, engine power at idle. The task will terminate at approximately V_1. The inflight scenarios will require an increase in engine power from trimmed, level flight, prior to an expedited climb. To reduce the effect of giving excessive emphasis to the engine control and monitoring task, the engine formats will only be visible during the time periods that you would normally view these displays. For the takeoff task, this will be a 4-second period following throttle advance, a 2-second period beginning at 55 knots (for the 60 knot power check), and a 2-second period beginning 5 knots prior to V_1. For the inflight case, a single 3-second period will be used.

For this test, your only task will be to control and monitor the aircraft engines. For each of the two display formats, you will be given 2 takeoff scenarios and 2 inflight scenarios. None of the scenarios will be repeated. Measurements will be taken in the form of quantitative (time, control lever position) and qualitative (questionnaire) data.

Training and Initial Subjective Evaluation

You will be provided approximately 2 hours of training prior to quantitative (recorded performance) data collection. For the initial portion of the training, a familiarization of the TSRV simulator, including the modern engine formats, will be provided. This familiarization will include takeoff and cruise situations using the velocity control wheel steering (VCWS) system. The training scenarios will provide situations similar to those that will be used during the actual test. After you become familiar with the simulated aircraft and aircraft systems, you will be asked to fill out a short questionnaire regarding the engine formats. Following this, familiarization time using the advanced formats will be provided. You will then be asked to fill out a second questionnaire.

During the last portion of the training, the engine displays will be switched on and off in the same manner that will be used during the quantitative data collection part of the test.

A summary of the critical engine parameters for the JT8D-7 engine is provided on the attached sheet. Prior to the test, you will be required to recall from memory, with 100% accuracy, all of these parameters. A sample of the test sheet for this requirement is also provided.

Display Formats

Modern format. The display elements used in this format should be generally familiar to you. The unique features of this format are as follows:

> Operation in a caution region: Any time that you are operating in a caution region, shown by a yellow range-marking on the display element, the digital readout for that display element will also be displayed in yellow.
>
> Operation in a warning region: Similar to operating in a caution except that the display color is red.
>
> EPR gauge: See figure A1.

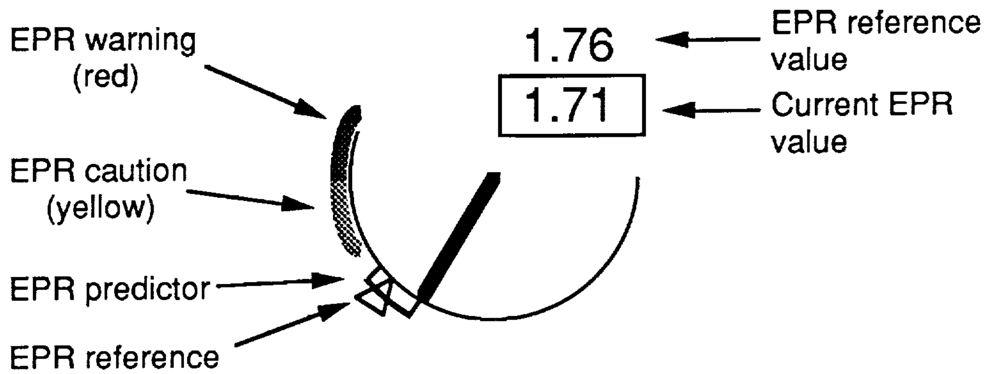

Figure A1. EPR gauge.

EPR warning limit: The EPR warning limit, shown by a red range-marking on the ERP dial, is a computed takeoff EPR limit (or maximum-continuous EPR if the takeoff and maximum-continuous limits are the same) based on current ambient conditions.

EPR caution limit: The EPR caution limit, shown by yellow range-marking on the EPR dial, is a computed maximum-continuous ERP limit based on current ambient conditions. If the takeoff and maximum-continuous limits are the same, no caution limit will be shown.

EPR reference pointer: For the takeoff conditions, an EPR reference pointer will be displayed on the EPR dials. The reference value itself will be digitally presented above the actual EPR value readout.

EPR predictor: The simulated engine fuel control computes an estimate of the EPR value based on current conditions. If the estimated and actual EPR values disagree (usually due to spoolup dynamics), an EPR predictor will be displayed on the EPR dial. The predictor will originate at the current EPR value and end at the estimated value.

Advanced format. The general form for the display elements used in this format are fixed-scales/moving-columns. The display elements themselves may be separated into 2 distinct cases: control and monitoring.

Control. The display elements for control are the thrust indicators (see fig. A2), scaled from −10% to +110%, and 100% defined as the maximum thrust available without exceeding any engine limit. The actual available thrust is shown, in pounds, at the top of each thrust indicator. In addition, the following elements are part of the thrust indicators:

Thrust warning limit: The thrust warning limit, shown by a red range-marking on the thrust scale, always begin at 100%. Under normal operations, no other engine parameter (N_1, N_2, or EGT) will be within a warning area unless the current thrust value is in the warning area.

Thrust caution limit: The thrust caution limit, shown by a yellow range-marking on the thrust scale, is based on a computed maximum-continuous thrust. Under normal operations, no other engine parameter (N_1, N_2, or EGT) will be within a caution area unless the current thrust value is in the caution area.

Thrust reference pointer: For the takeoff conditions, a thrust reference pointer will be displayed on each thrust indicator. The reference value itself, in percent of available thrust, will be digitally presented for a 5-second period immediately following a change in the reference value.

Thrust predictor: The monitoring system, independent of the engine, computes an estimate of the commanded thrust based on current conditions. This estimate is presented both as a predictor column and as a predictor pointer. The predictor pointer includes a digital readout, in percent of available thrust, of the predicted thrust.

Current thrust: The current thrust is displayed as a column on the thrust indicator. The color of the column will reflect the operating condition (green for normal, yellow for caution, and red for warning). Under steady-state situations, the thrust predictor and the current thrust values should be in general agreement.

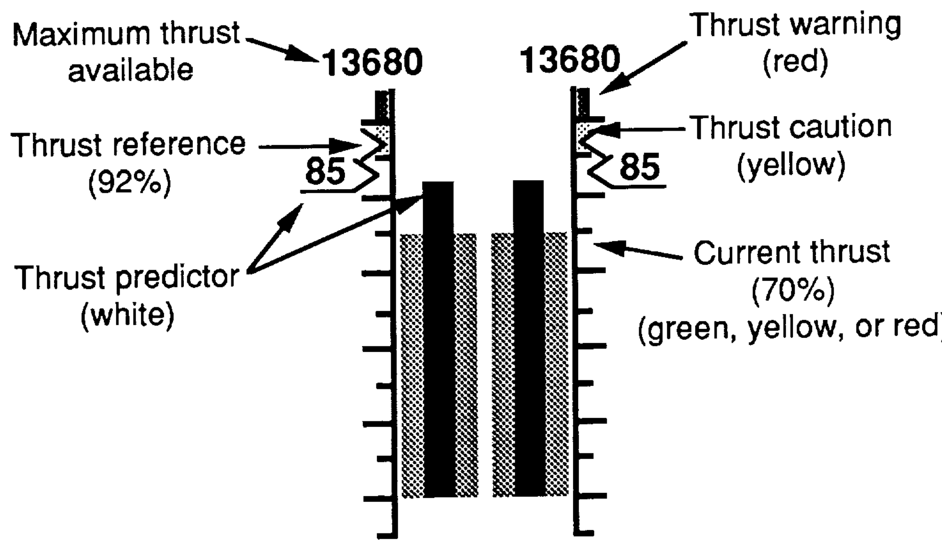

Figure A2. Thrust indicators.

Monitoring. The major display elements used for monitoring are column-deviation indicators. (See fig. A3.) In general, these indicators will show a difference between the actual value and an estimated value for each engine parameter. The indicators are divided into normal, caution, and warning ranges for differences both above and below the estimate. The ranges associated with the differences are as follows:

normal: 0 to 10%,

caution: 10 to 15%, and

warning: greater than 15%.

In addition, conventional limitations are merged with the deviations as the parameter approaches the limit. For example, the N_1 caution limit, which begins at 94% N_1, is merged with the N_1 deviation value beginning at 89% N_1. The merging is designed so that N_1 deviation column will just begin transitioning into the caution area as N_1 reaches 94%. The deviation columns are the color of the associated range. Each column-deviation indicator includes a digital presentation of the actual value. This digital readout will be the same color as the associated column.

Quantitative-Data Test Sequence

The quantitative-data part of this test will use both takeoff and inflight scenarios. Your only task will be to control and monitor the aircraft engines. For each of the two display formats, you will be given 2 takeoff scenarios and 2 inflight scenarios. None of the scenarios will be repeated.

For the takeoff task, you will be provided with the appropriate EPR or thrust reference settings and the V_1 speed. Your task for this situation is to set takeoff power and monitor the engine systems. The data collection will begin at the time you advance the throttles. From the time of throttle advance, you will have 4 seconds to set the takeoff power and monitor the engine systems. The engine displays will blank at the end of this 4-second period. According to the Boeing takeoff checklist, you should adjust takeoff power before 60 knots. To allow you to do this, the engine displays will be turned on at 55 knots for a 2-second period. The displays will again be turned on for a 2-second period beginning 5 knots prior to V_1 for a final systems check. Performance measures will include control activity and the accuracy in setting takeoff power. If any unusual or abnormal engine response is noted, you should announce "abort takeoff."

The inflight task will be for you to increase engine power to approximately maximum, as though you were anticipating an expedited climb. For these scenarios, you will have a single 3-second period to both set the engine power and monitor the engine systems.

A general questionnaire will be completed immediately after the quantitative-data test sequence.

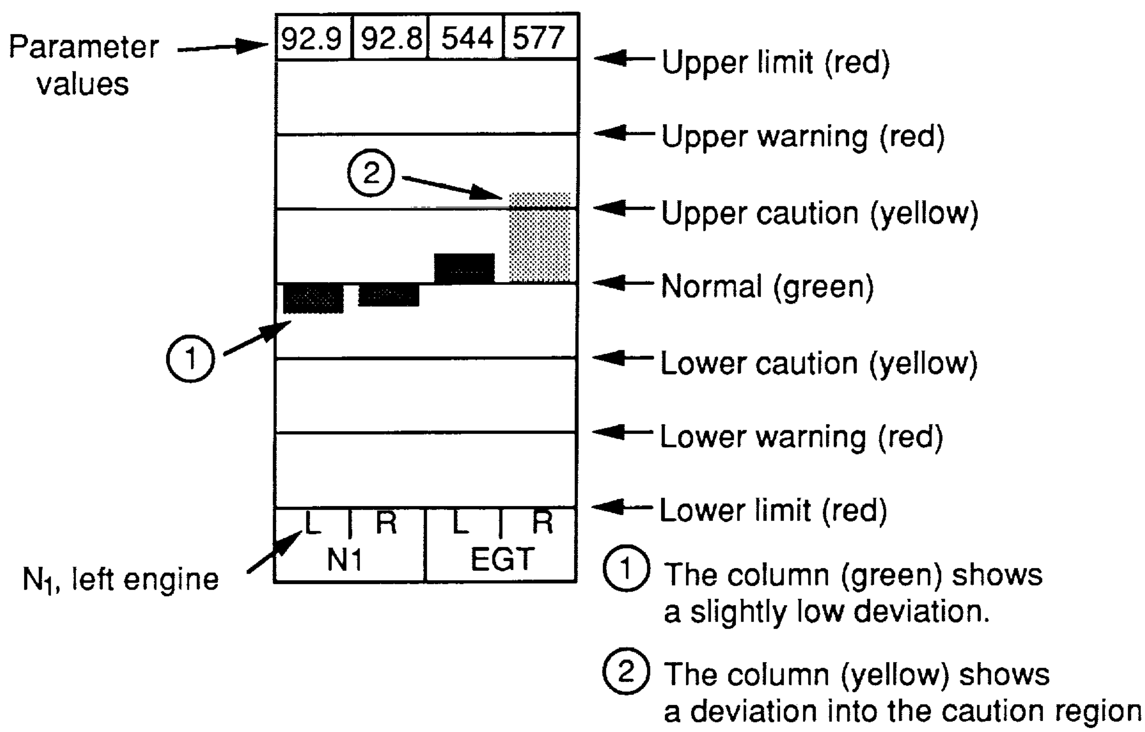

Figure A3. Representative monitoring indicators.

Critical Engine Parameters for the JT8D-7 Engine

EPR and THRUST limits:	EPR and thrust limits are automatically computed and displayed. For takeoff, however, the takeoff performance chart should be consulted for power limits.
N_1 limits:	Normal – 0 to 94 percent Caution – 94 to 100.1 percent Warning – above 100.1 percent
EGT limits:	Normal – below 535°C Caution – 535°C to 570°C Warning – above 570°C
N_2 limits:	Normal – 0 to 94 percent Caution – 94 to 100.0 percent Warning – above 100.0 percent
Oil pressure:	Warning – below 35 psi Caution – 35 to 40 psi Normal – 40 to 55 psi Warning – above 55 psi
Oil temperature:	Warning – below 40°C Normal – 40°C to 120°C Caution – 120°C to 157°C Warning – above 157°C
Oil quantity:	Warning – below 1.0 gal Normal – above 1.0 gal

Appendix B

Quiz of Critical Engine Parameters

The following quiz will test your knowledge of the critical engine parameters for the JT8D-7 engine. This information would be expected to be committed to memory by any pilot operating an aircraft using these engines. This is a "from memory only" quiz. A score of 100-percent accuracy is required to participate as a subject.

1. The NORMAL N_1 operating range is ____ to ____ percent.
2. The CAUTION N_1 operating range is ____ to ____ percent.
3. The WARNING N_1 operating range is anything above ____ percent.
4. The NORMAL N_2 operating range is ____ to ____ percent.
5. The CAUTION N_2 operating range is ____ to ____ percent.
6. The WARNING N_2 operating range is anything above ____ percent.
7. The NORMAL EGT operating range is anything below ____ °C.
8. The CAUTION EGT operating range is ____ °C to ____ °C.
9. The WARNING EGT operating range is anything above ____ °C.
10. The NORMAL OIL PRESSURE operating range is ____ to ____ psi.
11. The CAUTION OIL PRESSURE operating range is ____ to ____ psi.
12. The WARNING OIL PRESSURE operating range is below ____ or above ____ psi.
13. The NORMAL OIL TEMPERATURE operating range is ____ °C to ____ °C.
14. The CAUTION OIL TEMPERATURE operating range is ____ °C to ____ °C.
15. The WARNING OIL TEMPERATURE operating range is below ____ °C or above ____ °C.
16. The NORMAL OIL QUANTITY operating range is anything above ____ gal.
17. The WARNING OIL QUANTITY operating range is anything below ____ gal.

Appendix C

Pilot Questionnaires

The questionnaires were administered in the following sequence:

1. Questionnaire A was administered after the pilot familiarization and provided for the qualitative evaluation of the modern format.
2. Questionnaire B was administered after the pilot familiarization and provided for the qualitative evaluation of the E-MACS format.
3. Questionnaire C was administered immediately after questionnaire B and provided for the qualitative comparison of the two display formats.
4. Questionnaires C and D (general comments) were administered after the quantitative evaluation.

Definitions used in the questionnaires:

advanced format	engine display format designed for this study (E-MACS)
modern format	current technology, state-of-the-art, engine display format

Questionnaire A

This is a check-the-block questionnaire. For each question, mark your answer inside the block that best describes your opinion.

Definitions:

extremely accurate: no perceived error

fairly accurate: minor but insignificant error

extremely easy: intuitive, no mental effort is required to use

fairly easy: minor mental work load, some thought is required to use

extremely rapid: instantaneous, one input

fairly rapid: one large input followed one or two minor corrections

1. Overall, how easy did you find this display format to use?

|_____|_____|_____|_____|_____|

Extremely easy   Fairly easy

2. How easy did you find the display element for control (EPR) to use?

|_____|_____|_____|_____|_____|

Extremely easy   Fairly easy

3. How rapidly were you able to set engine power?

|_____|_____|_____|_____|_____|

Extremely rapid   Fairly rapid

4. How accurately were you able to set engine power?

|_____|_____|_____|_____|_____|

Extremely accurate   Fairly accurate

5. How easy did you find the display elements for monitoring (engine health) to use?

|_____|_____|_____|_____|_____|

Extremely easy   Fairly easy

6. How rapidly were you able to detect an out-of-tolerance condition?

|_____|_____|_____|_____|_____|

Extremely rapid   Fairly rapid

Questionnaire B

This is a check-the-block questionnaire. For each question, mark your answer inside the block that best describes your opinion.

Definitions:

extremely accurate: no perceived error

fairly accurate: minor but insignificant error

extremely easy: intuitive, no mental effort is required to use

fairly easy: minor mental work load, some thought is required to use

extremely rapid: instantaneous, one input

fairly rapid: one large input followed one or two minor corrections

1. Overall, how easy did you find this display format to use?

   Extremely easy — Fairly easy

2. How easy did you find the display element for control (thrust) to use?

   Extremely easy — Fairly easy

3. How rapidly were you able to set engine power?

   Extremely rapid — Fairly rapid

4. How accurately were you able to set engine power?

   Extremely accurate — Fairly accurate

5. How easy did you find the display elements for monitoring (engine health) to use?

   Extremely easy — Fairly easy

6. How rapidly were you able to detect an out-of-tolerance condition?

   Extremely rapid — Fairly rapid

Questionnaire C

This is a check-the-block questionnaire. For each question, mark your answer inside the block that best describes your opinion.

1. Overall, which display format did you find easier to use?

|___|___|___|___|___|

Modern easier — No difference — Advanced easier

2. For which display format did you find engine control easier?

|___|___|___|___|___|

Modern easier — No difference — Advanced easier

3. Which display format allowed the faster setting of engine power?

|___|___|___|___|___|

Modern faster — No difference — Advanced faster

4. Which display format allowed the more accurate setting of engine power?

|___|___|___|___|___|

Modern more accurate — No difference — Advanced more accurate

5. For which display format did you find engine monitoring easier?

|___|___|___|___|___|

Modern easier — No difference — Advanced easier

6. Which display format allowed the faster detection of out-of-tolerance conditions?

|___|___|___|___|___|

Modern faster — No difference — Advanced faster

Questionnaire D

Regarding the advanced display only, please provide a short answer to each of the following questions:

1. In general, what did you like or dislike about this format?

____
____
____
____

2. What did you like or dislike about the thrust display element?

____
____
____
____

3. What did you like or dislike about the monitoring display elements?

____
____
____
____

4. If you have any additional comments, please include them here.

____
____
____
____

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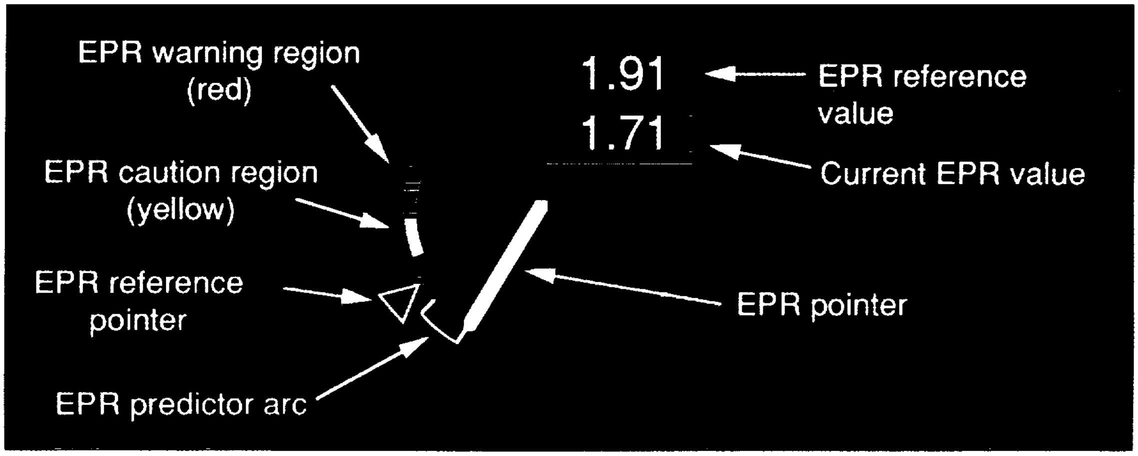

Figure 1. EPR gauge.

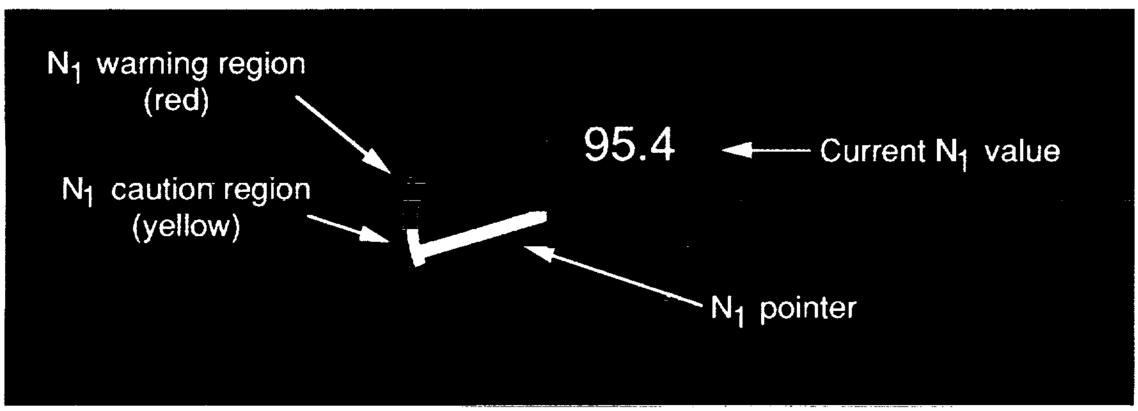

Figure 2. N_1 gauge.

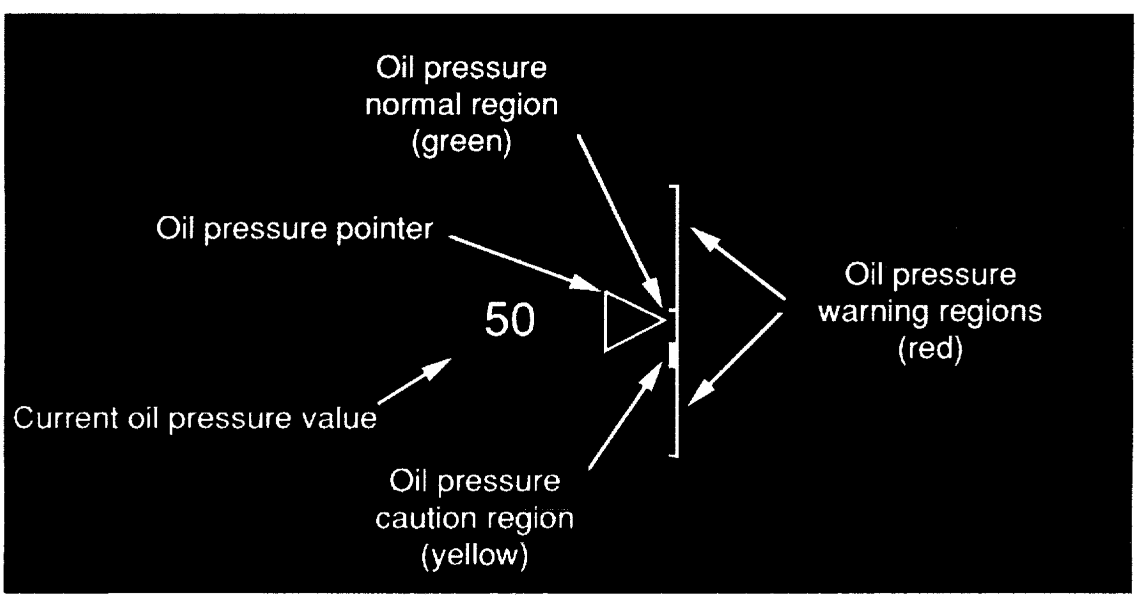

Figure 3. Oil pressure gauge.

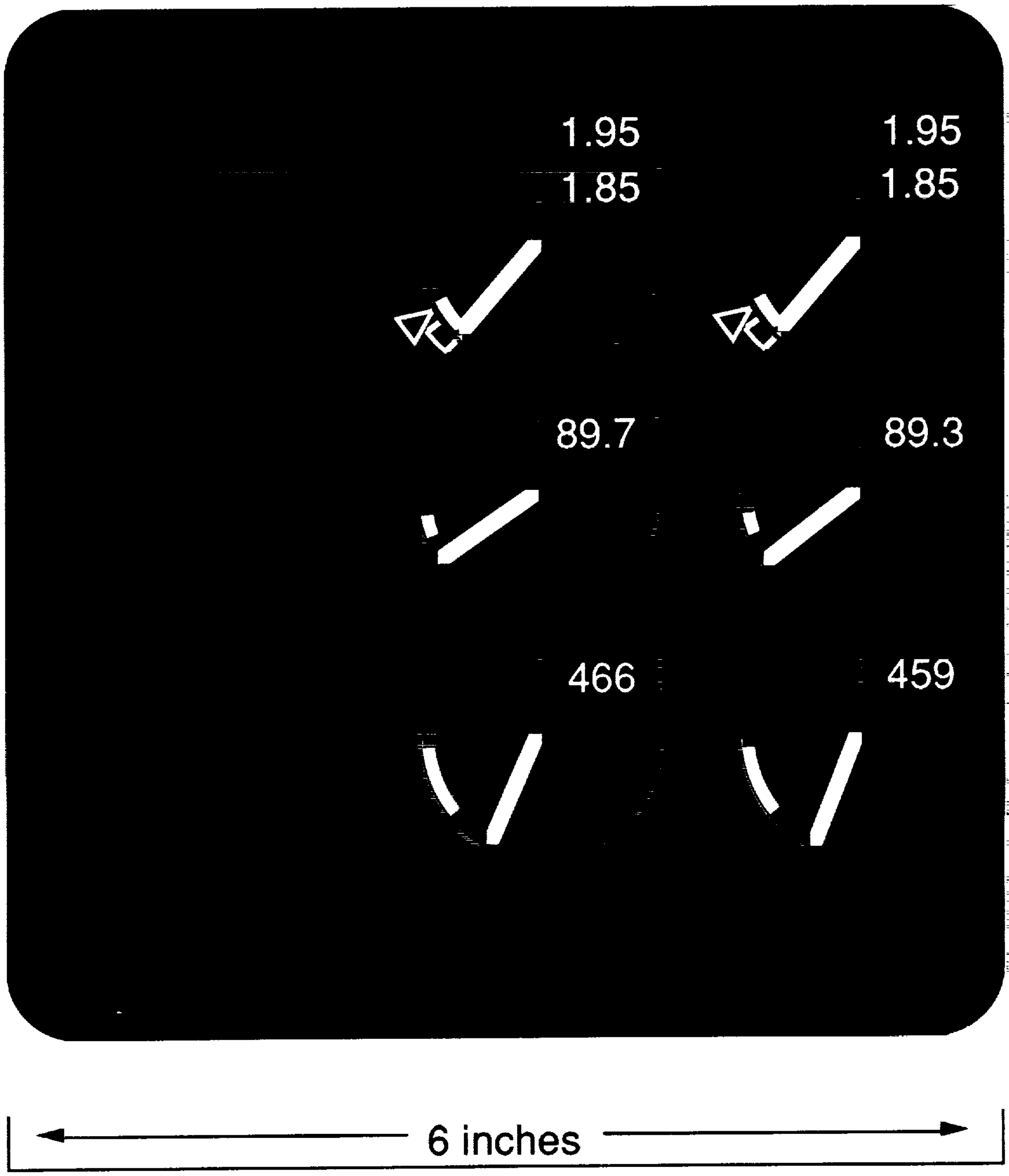

Figure 4. Traditional display, left CRT.

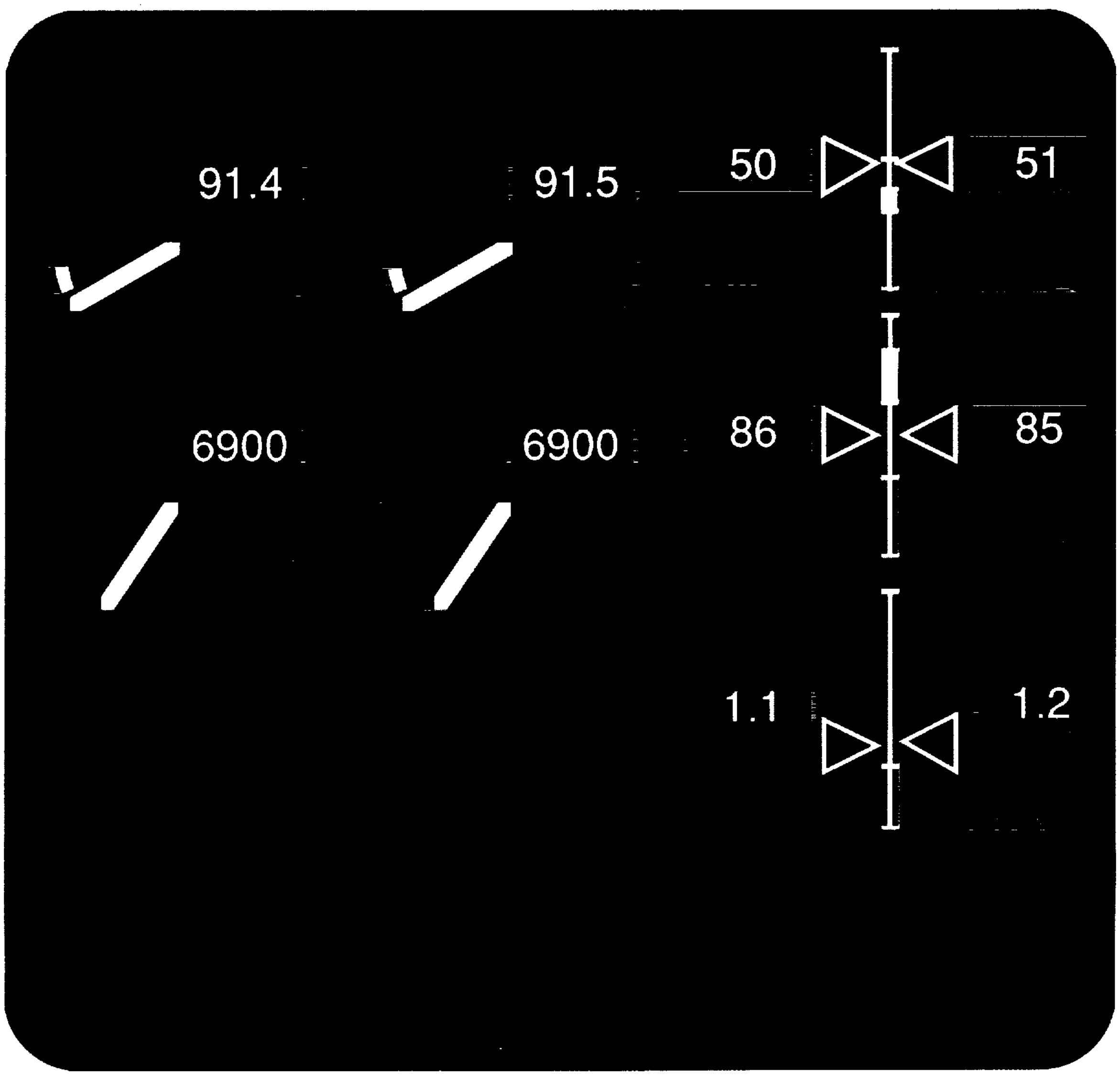

Figure 5. Traditional display, right CRT.

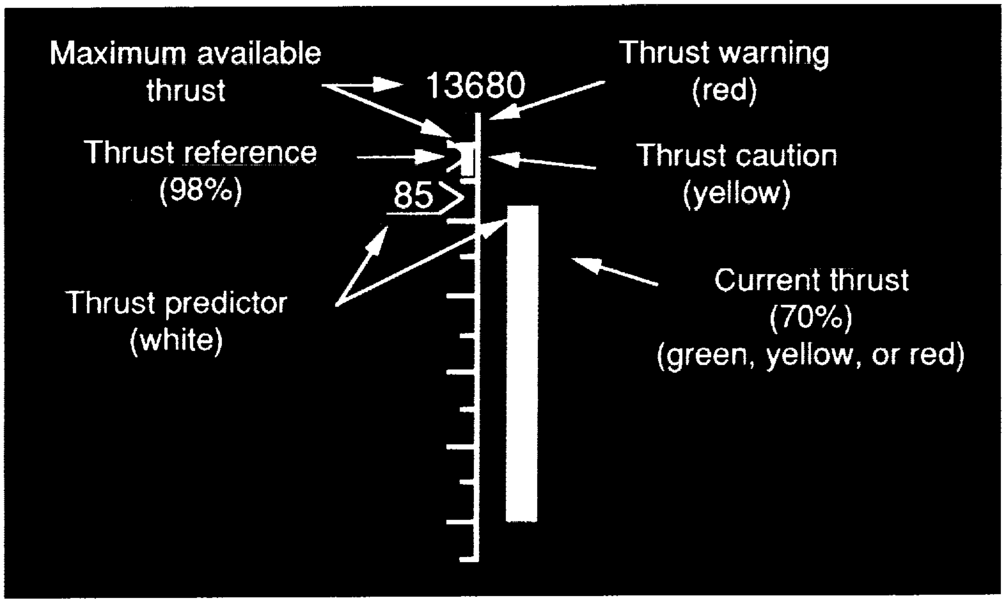

Figure 6. Thrust indicator.

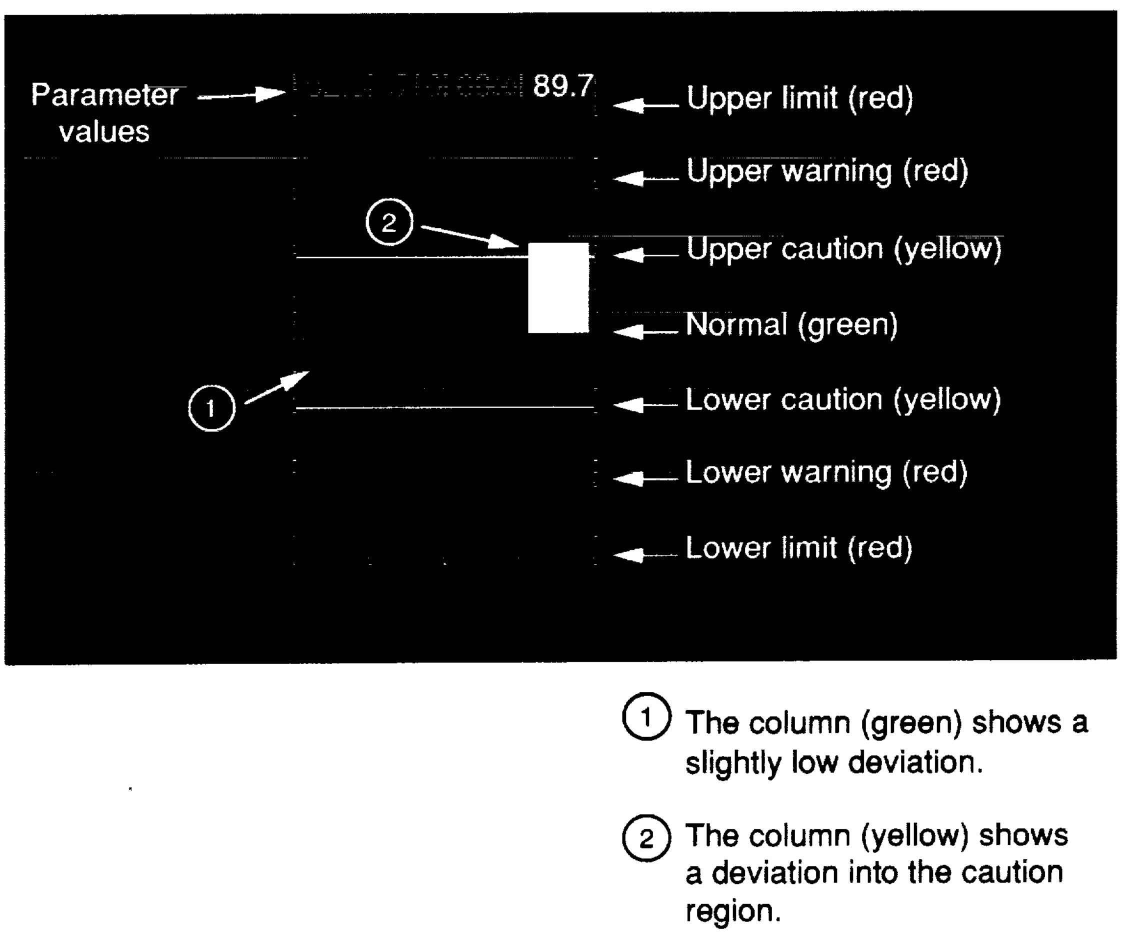

Figure 7. Example of the monitoring display elements.

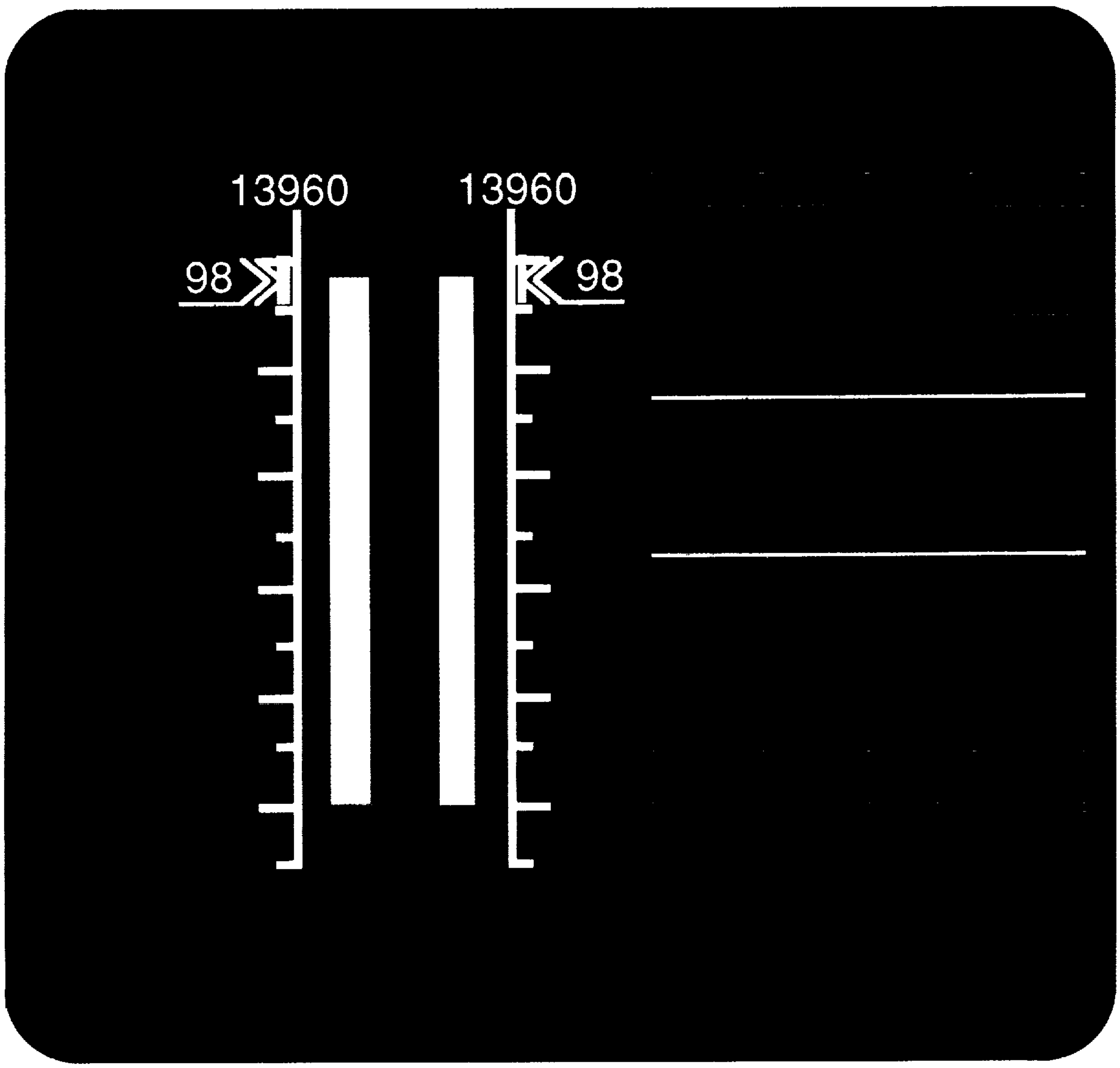

Figure 8. E-MACS display, left CRT.

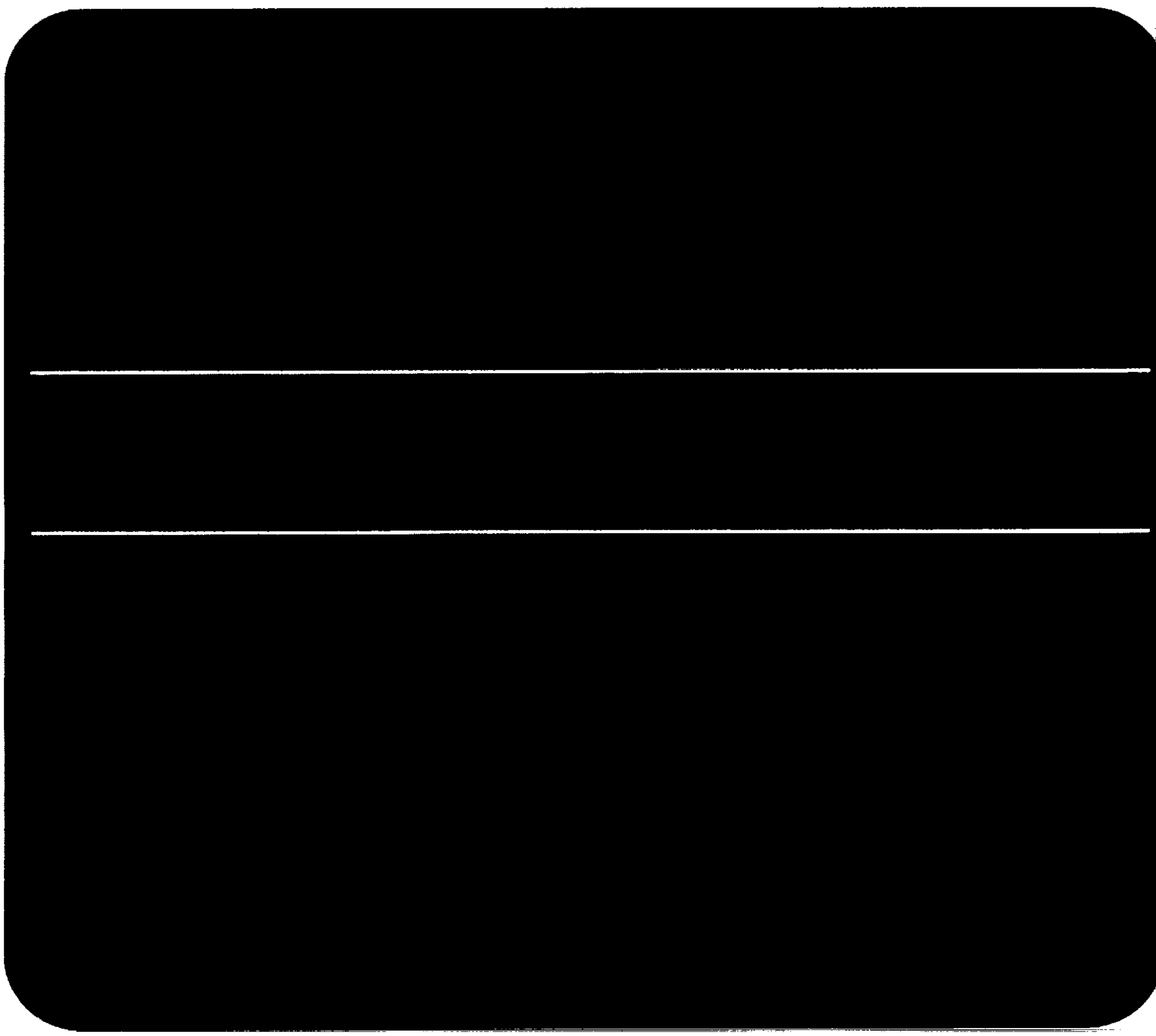

Figure 9. E-MACS display, right CRT.

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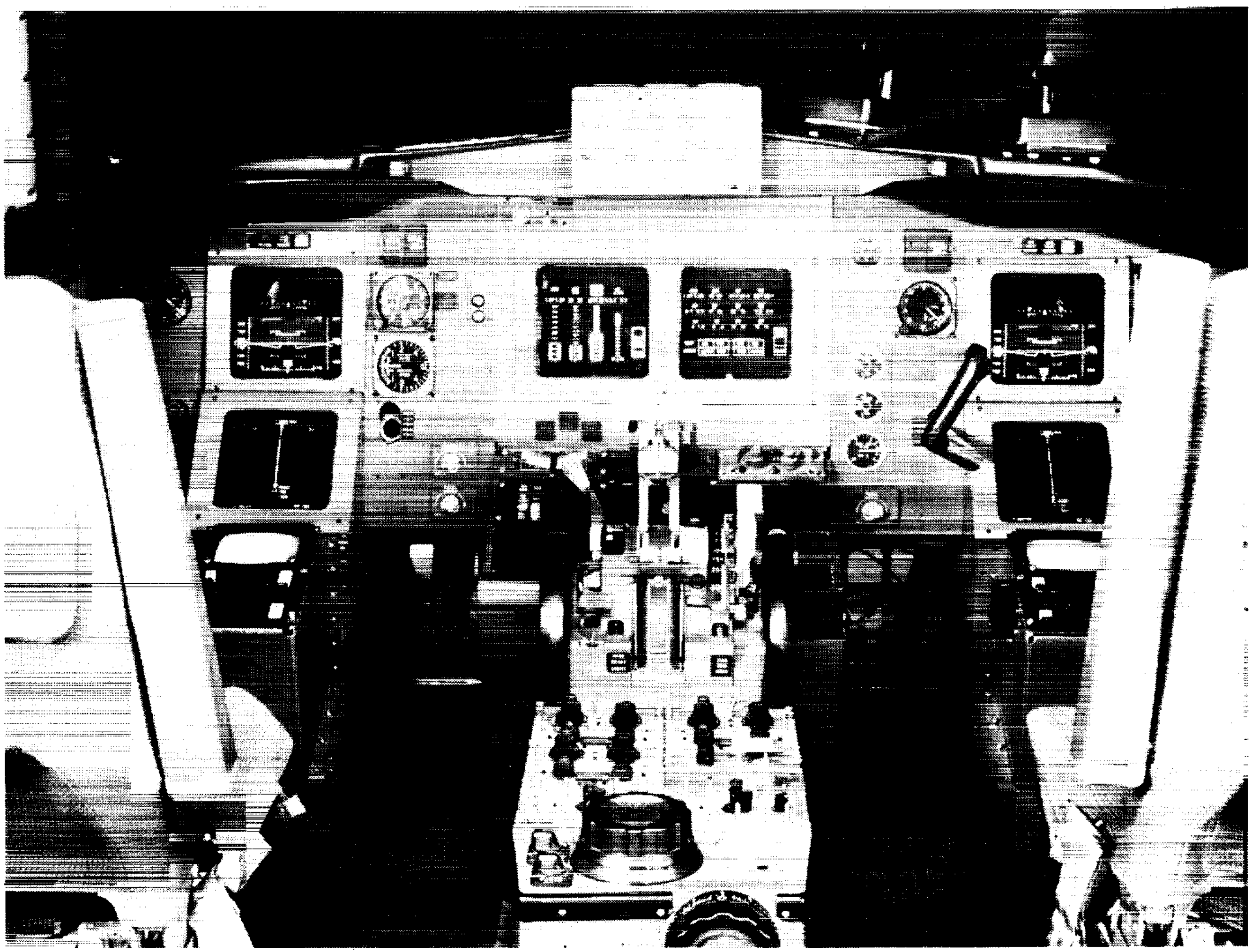

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Figure 10. Simulator cockpit.

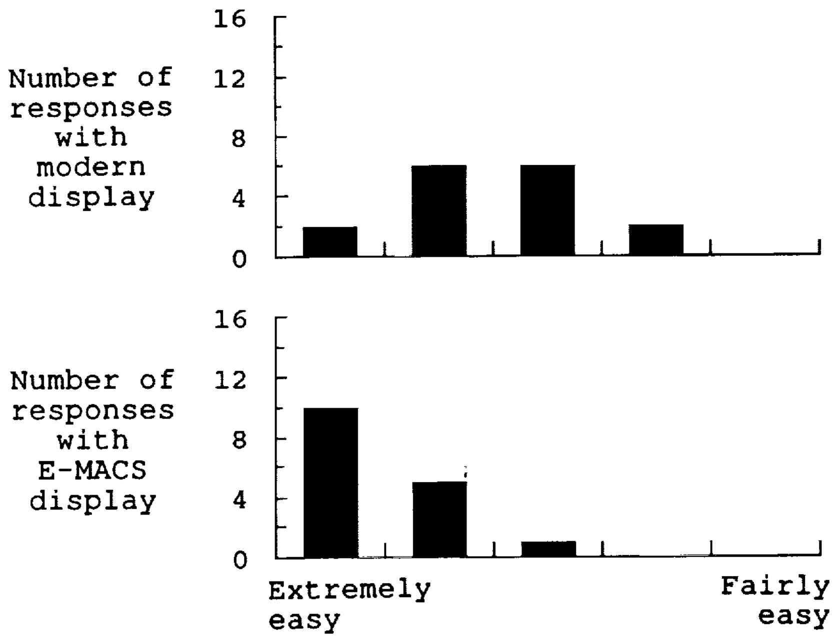

Figure 11. Responses to question 1 of questionnaires A and B. (Question 1: Overall, how easy did you find this display format to use?)

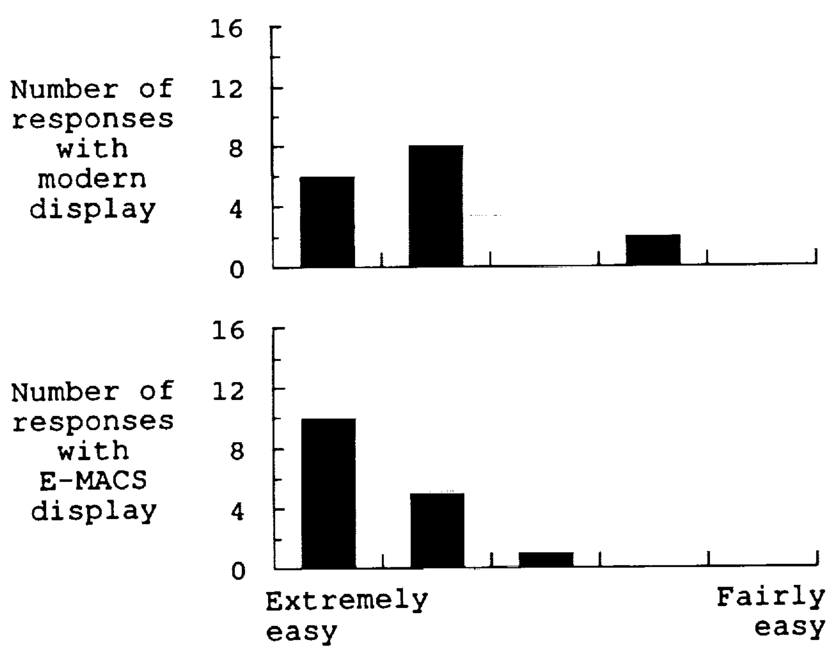

Figure 12. Responses to question 2 of questionnaires A and B. (Question 2: How easy did you find the display element for control to use?)

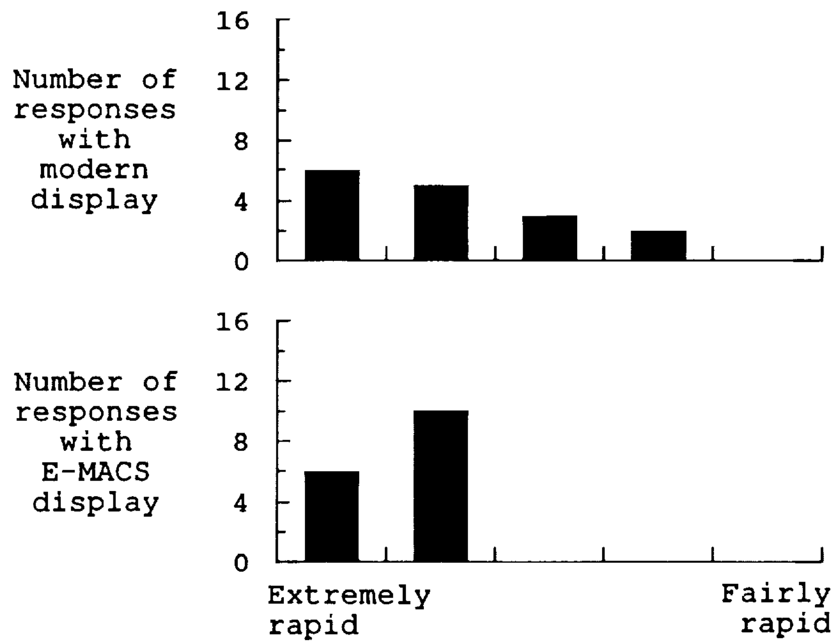

Figure 13. Responses to question 3 of questionnaires A and B. (Question 3: How rapidly were you able to set engine power?)

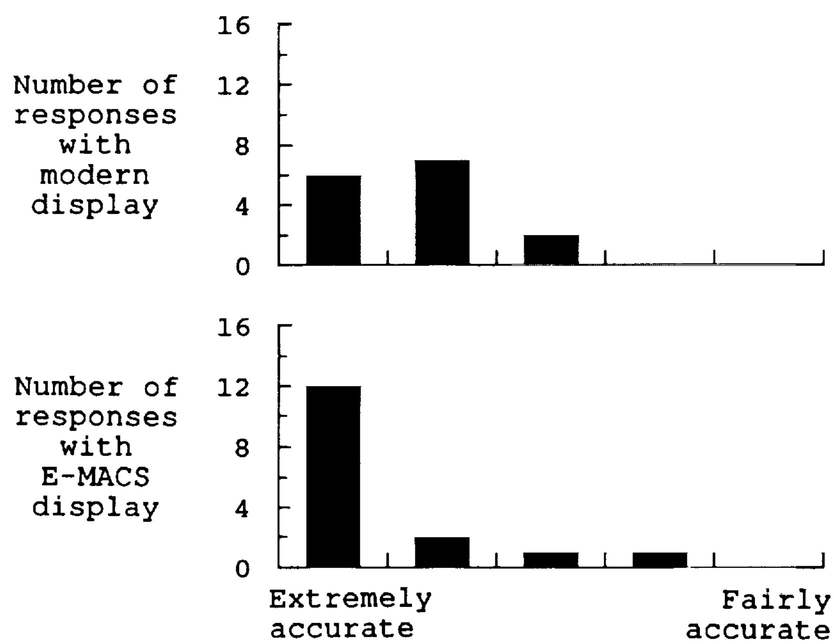

Figure 14. Responses to question 4 of questionnaires A and B. (Question 4: How accurately were you able to set engine power?)

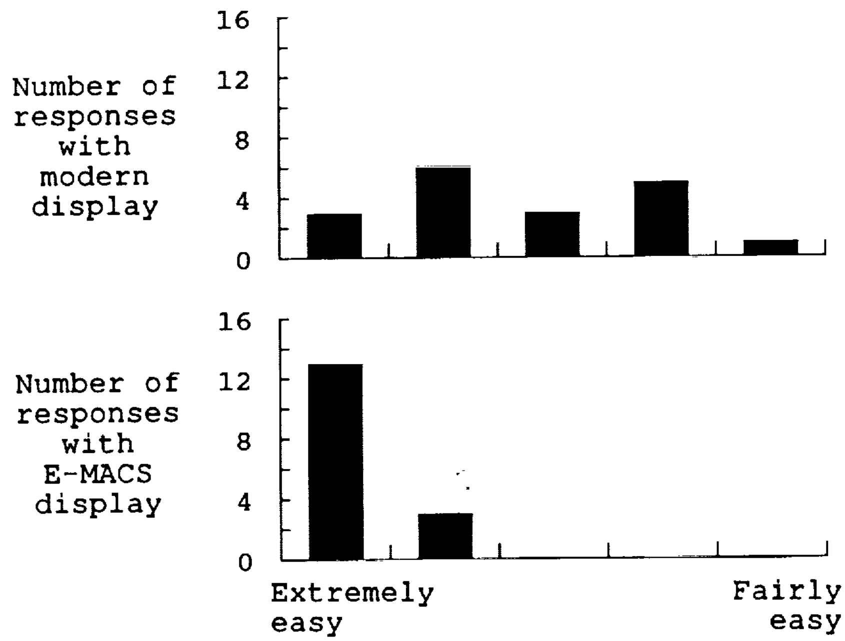

Figure 15. Responses to question 5 of questionnaires A and B. (Question 5: How easy did you find the display elements for monitoring engine health to use?)

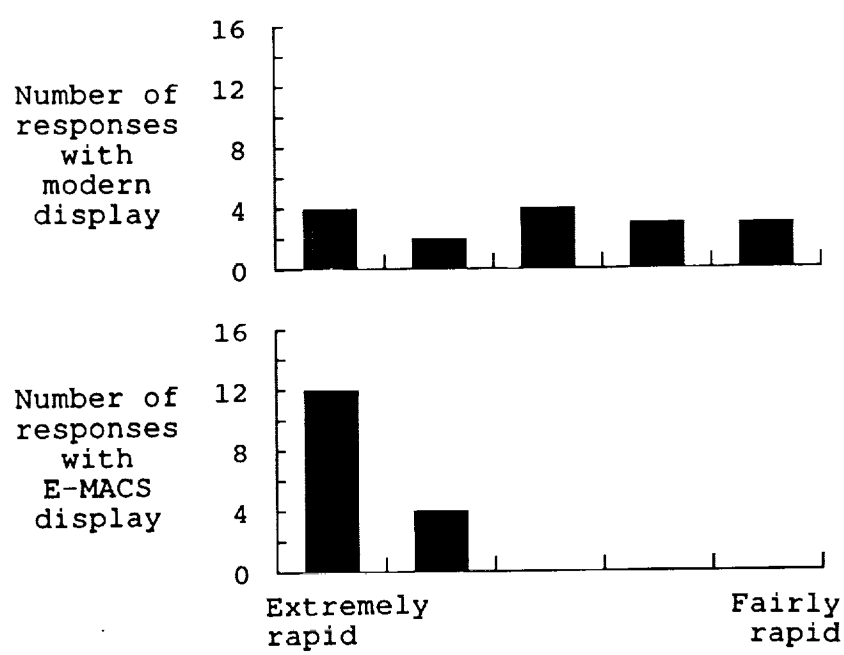

Figure 16. Responses to question 6 of questionnaires A and B. (Question 6: How rapidly were you able to detect an out-of-tolerance condition?)

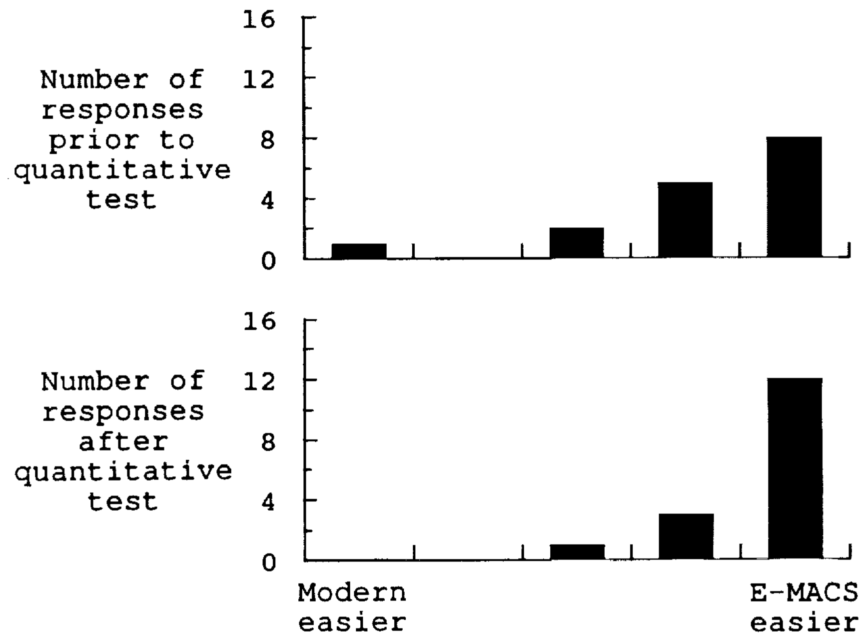

Figure 17. Responses to question 1 of questionnaire C. (Question 1: Overall, which display format did you find easier to use?)

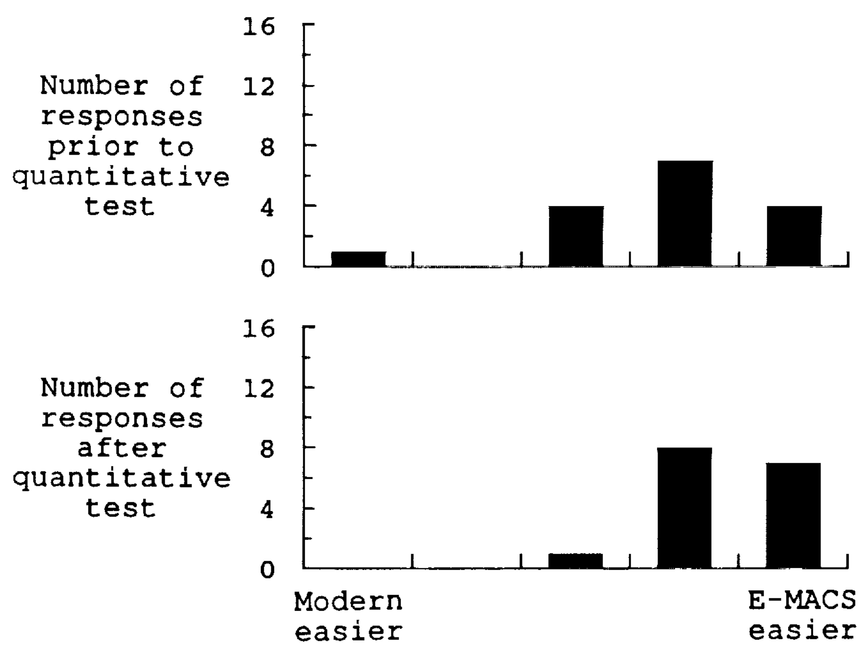

Figure 18. Responses to question 2 of questionnaire C. (Question 2: For which display format did you find engine control easier?)

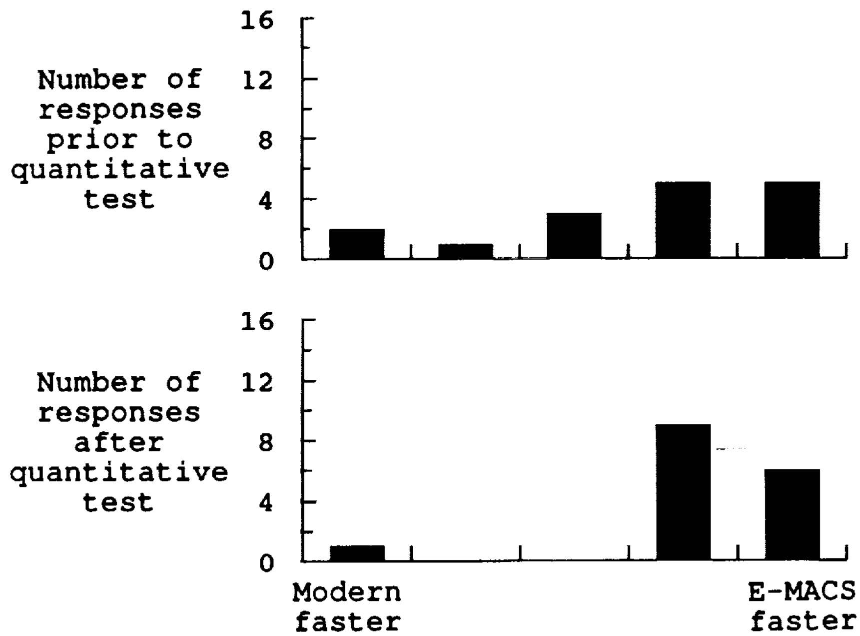

Figure 19. Responses to question 3 of questionnaire C. (Question 3: Which display format allowed the faster setting of engine power?)

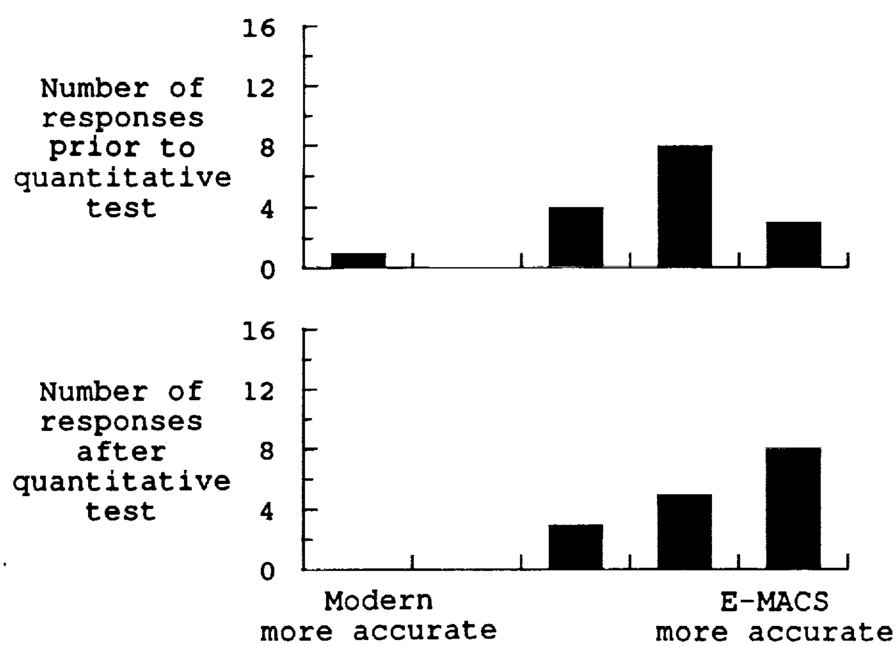

Figure 20. Responses to question 4 of questionnaire C. (Question 4: Which display format allowed the more accurate setting of engine power?)

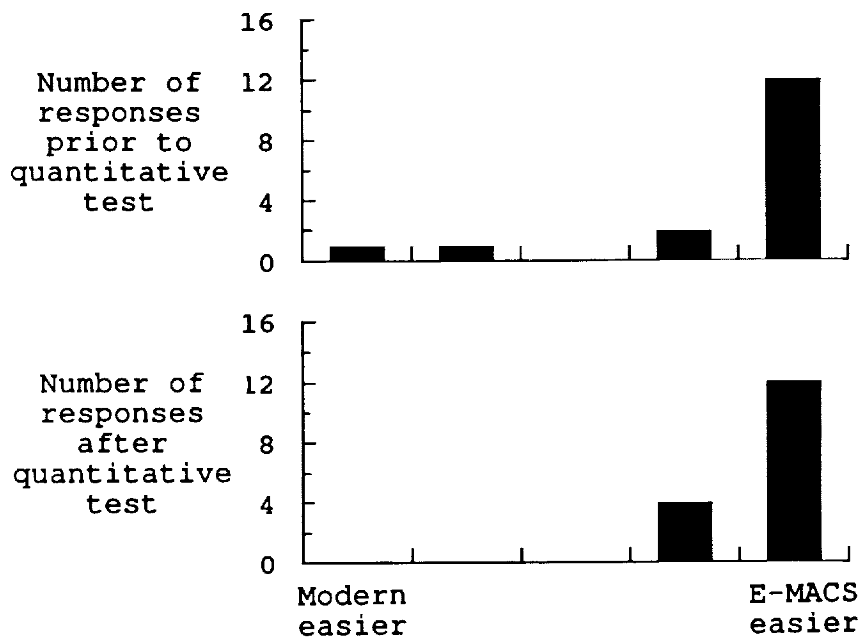

Figure 21. Responses to question 5 of questionnaire C. (Question 5: For which display format did you find engine monitoring easier?)

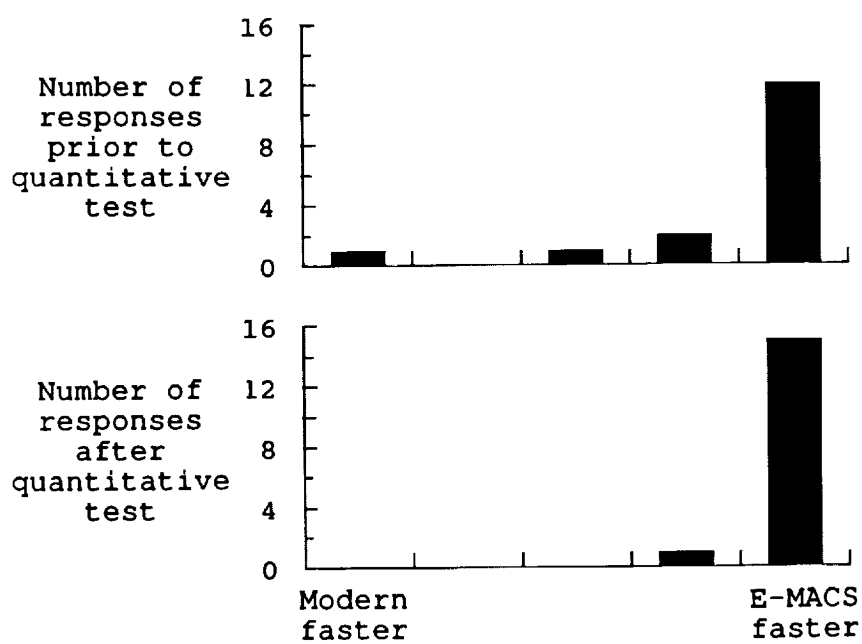

Figure 22. Responses to question 6 of questionnaire C. (Question 6: Which display format allowed the faster detection of out-of-tolerance conditions?)

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16. Abstract

The Engine Monitoring and Control System (E-MACS) display is a new concept for an engine instrument display, the purpose of which is to provide an enhanced means for a pilot to control and monitor aircraft engine performance. It provides graphically presented information about performance capabilities, current performance, and engine component or subsystem operational conditions relative to nominal conditions. The concept was evaluated by 16 pilots against a traditional, state-of-the-art, electronic engine display format. The results of this evaluation showed a substantial pilot preference for the E-MACS display relative to the traditional display. The results of the failure-detection portion of the evaluation showed a 100-percent detection rate for the E-MACS display relative to a 57-percent rate for the traditional display. From these results, it is concluded that by providing this type of information in the cockpit, a reduction in pilot work load and an enhanced ability for detecting degraded or off-nominal conditions is probable, thus leading to an increase in operational safety.

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