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Simulator Evaluation of a Display for a Takeoff Performance Monitoring System

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Summary

A Takeoff Performance Monitoring System (TOPMS) has been developed to provide the pilot with graphic and numeric information pertinent to his decision to continue or abort a takeoff. The TOPMS information display consists primarily of a runway graphic overlaid with symbolic status, situation, and advisory information including (1) current position and airspeed, (2) predicted locations for reaching decision speed V_1 and rotation speed V_R, (3) ground-roll limit for reaching V_R, (4) predicted stop point for an aborted takeoff from current conditions, (5) engine status flags, and (6) an overall situation advisory flag that recommends continuation or rejection of the takeoff.

In the present study, 32 experienced multiengine-rated pilots evaluated the TOPMS on the Langley Transport Systems Research Vehicle (TSRV) Real-Time Simulator. They stated that the algorithm provided very valuable real-time information and that the display was easy to monitor and comprehend. Twenty-five of the pilots formally rated the system with a modified Cooper-Harper-type rating diagram. They gave the system an average rating of 3 or "satisfactory—good" (on a 1–10 scale, where 1 relates to "satisfactory—excellent").

Additional study results included a consensus by the pilots that

1. Primary responsibility for monitoring the TOPMS (and reporting anomalies to the other pilot) should be assigned to the pilot not flying.
2. Location of the head-down TOPMS display close to the pilot's look direction (out the window) would be preferred; however, a lower location such as that used in this simulation study is acceptable.
3. The pilot flying should have some form of the display available for reference; ideally, a simplified version implemented as a head-up display (HUD) would enhance his awareness of the situation as he focused his main attention to the runway scene ahead.

All the evaluation pilots expressed a desire to have a TOPMS-type display in their cockpit because it would provide valuable safety-related information not currently available during takeoff. A number of specific comments and recommendations relative to the symbology were also made. It was concluded that several of the suggestions should be incorporated and the system reevaluated on the simulator before submitting it to flight test. It was also concluded that a TOPMS HUD should be implemented and evaluated on the simulator along with the modified head-down configuration.

Introduction

Current flight management systems generally do not provide any "Go/Abort" decision aids during takeoff. Yet, statistics compiled over the years indicate that takeoff accidents account for about 12 percent of all aircraft accidents. In recent years, the accident rate during takeoff has remained constant at about 2 per million flights, whereas the rate for all aircraft-related accidents over the same time period has decreased (ref. 1).

Most takeoff-related accidents are attributable to some form of performance degradation. A large percentage of them could have been avoided had there been some way to monitor the progress of the takeoff roll (ref. 1). Several performance monitoring systems with various complexities have been proposed. Single-point speed-check methods have been proposed (ref. 2), as well as some that deal with elapsed time to reach a point on the runway (ref. 1). Also, a multiparameter aircraft performance-margin indicator (ref. 3) has been conceived that continuously determines the ability of the airplane to achieve rotation speed (viz, V_R) and to brake to a stop within specified runway constraints. It does not, however, directly indicate where on the runway the airplane will reach V_R or where it can be brought to a stop, but it does continuously show the pilot how close he is to losing his takeoff or his abort option.

The Takeoff Performance Monitoring System (TOPMS) evaluated in this study was formulated and analyzed in batch simulation at the Langley Research Center (refs. 4, 5, and 6) under a cooperative agreement with the University of Kansas. This system incorporates the following features:

1. It calculates the minimum length of runway recommended for takeoff under existing conditions (viz, the "Balanced Field Length (BFL)" specified by the Federal Aviation Administration (FAA) (ref. 7)).
2. It determines the runway distance consumed as well as the remaining distance required to achieve rotation speed; it also determines the limiting position for reaching V_R as part of the BFL calculation.
3. It calculates the runway distance required for stopping the airplane from its present speed on the existing type of surface with maximum wheel braking (i.e., "autobraking"), fully deployed spoilers, but no reverse thrust. Once an abort is underway, it also calculates a stopping distance by using the current level of measured acceleration (due to, for example, braking, drag, reverse thrust).
4. It creates a graphic of the assigned runway and shows, in real time, where important events (such as predicted stop point) will occur.

5. It monitors engine pressure ratios (EPR) for each engine and relates them to a reference value for the throttle settings used; deviations beyond limits specified in the TOPMS algorithm activate engine-failure flags.

6. It samples and analyzes acceleration and other pertinent parameters and summarizes its findings with a prominent "Go/Abort" or "Situation Advisory Flag."

An additional feature of the TOPMS is that it can be implemented entirely in the airplane; therefore, it is not dependent on any airport-based equipment. However, it is dependent on specific runway data, such as runway length, direction, and slope.

This report describes the system and display developed to convey this information to the pilot and documents a pilot-in-the-loop evaluation of the display using the Langley Transport Systems Research Vehicle (TSRV) Real-Time Simulator. The TSRV (ref. 8) is a twin jet airplane in the Boeing 737 class. In the sections that follow, the TOPMS algorithm is briefly described, the display format and symbology are explained, the simulator and simulation are described, and the results of the simulator evaluation are discussed. The results consist of both pilot ratings of the displays and their supporting comments including recommendations.

Nomenclature

BFL	balanced field length (minimum recommended for given conditions)
CAS	calibrated airspeed
CRT	cathode-ray tube
EPR	engine pressure ratio
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GRLL	ground-roll limit line
HUD	head-up display
NASA	National Aeronautics and Space Administration
NCDU	Navigation Control Display Unit
ND	Navigation Display
PFD	Primary Flight Display
$s_0, \ldots, s_3$	incremental distances on runway (see fig. 2)
SAF	Situation Advisory Flag
TOPMS	Takeoff Performance Monitoring System
TSRV	Transport Systems Research Vehicle (Boeing 737 class)
V_1	decision speed; limit of where pilot can opt to takeoff or abort
V_2	second segment climb speed
V_R	rotation speed; pilot initiates rotation upon reaching this speed

Description of Takeoff Performance Monitoring System

TOPMS Algorithm

The algorithm consists of two main parts: a pretakeoff segment and a real-time segment, as shown by the block diagram in figure 1. The pretakeoff segment calculates airplane-trim values, nominal performance parameters, and the BFL metric. The real-time segment assesses takeoff progress and system status based on measured performance and the precalculated nominal performance. It also computes the parameter values that drive the display.

The pretakeoff segment uses detailed engine, aerodynamic, and landing gear models in conjunction with a typical takeoff-throttle-movement history to generate a set of nominal airplane performance values (ref. 4). In order to do this, the algorithm requires the inputs specified in table 1. These inputs are entered either manually (via keyboard) by the crew or are input automatically by appropriate onboard systems (e.g., a computer or data bus).

Table 1. Inputs for TOPMS Pretakeoff Segment

Airplane center of gravity
Airplane gross weight
Airplane flap setting
Ambient temperature
Pressure altitude
Wind direction
Wind speed
Runway rolling-friction coefficient

The pretakeoff segment computes (1) the runway distance s_0 required to reach decision speed V_1, (2) the runway distance s_3 required to bring the airplane to a complete stop from V_1, (3) the runway distance s_1 required to reach rotation speed V_R from V_1 with one engine failed, and (4) the ground-air distance s_2 required to attain a specified height (35 feet used in this study) at the departure end of the runway from the V_R point after experiencing an engine failure at V_1. These distances are shown in figure 2

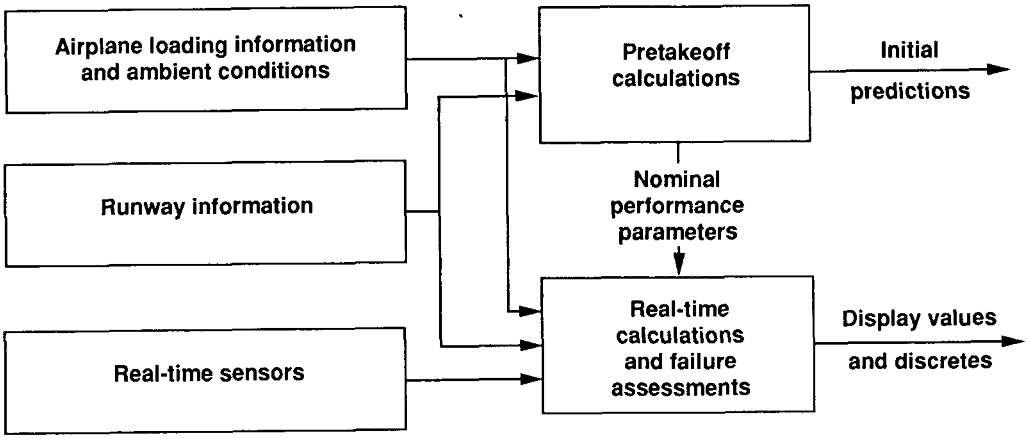

Figure 1. Diagram of TOPMS Algorithm Functions.

for the case where s_3 is less than $s_1 + s_2$. (The distance s_3 could be greater (e.g., if the runway was icy).) The initial ground-roll distance from the brake release point to the point where the engine failure occurs plus the greater of $s_1 + s_2$ or s_3 constitutes an important metric called Balanced Field Length (BFL) or a reference minimum runway length required for the particular airplane under the existing conditions. A ground-roll limit distance to reach V_R is then computed by subtracting s_2 from the total runway length.

After the pretakeoff computations are complete, the pilot enters the length and direction of the assigned runway and how far from the threshold the takeoff roll will begin (i.e., "runway offset"). The algorithm generates the set of nominal performance values for the current takeoff based on the estimated runway rolling friction coefficient that was entered for the pretakeoff calculations. During the takeoff roll, the algorithm accepts the measured inputs listed in table 2 and continually calculates the present position of the airplane on the runway, the runway distance needed to achieve rotation speed, and the runway distance needed to bring the airplane to a complete stop. After allowing the engine dynamics due to throttle movement to stabilize, the runway rolling friction coefficient and the nominal performance values are recomputed. This is a unique computational feature that can be performed several times (e.g., if the runway was partly dry and partly slushy); however, in this study the recalculation was only performed once. The real-time segment also monitors the "health" of the engines.

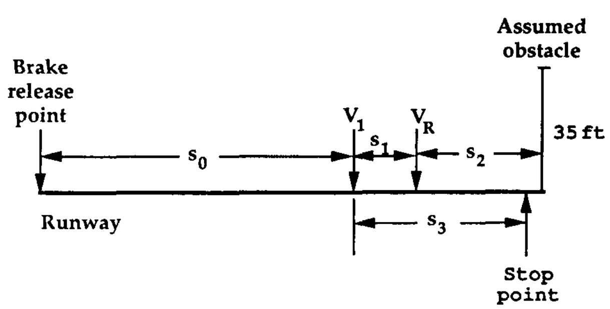

Figure 2. Incremental runway distances.

Table 2. Measured Inputs to Real-Time Segment

Airplane flap setting
Left and right throttle positions
Left and right engine pressure ratios
Airplane calibrated airspeed
Airplane accelerations
Airplane ground speed

Display Format and Symbology

Figure 3 shows the location of the TOPMS display (CRT near the center of the photograph) in the TSRV cockpit. The TOPMS display appears on the Navigation Display (ND) prior to and during the takeoff. Immediately following main wheel liftoff, the TOPMS display disappears and the normal map and navigation information automatically returns to the ND screen.

The TOPMS display consists of a runway graphic with passive and active symbology superimposed over and around it. This is illustrated in figure 4 for both takeoff and abort.

The left side of figure 4 shows an airplane on a 6000-foot runway nearing its decision speed V_1 (predicted to occur at the horizontal V_1 line shown). The nose of the airplane symbol indicates the present longitudinal position of the airplane, and its calibrated airspeed (CAS) appears in the box to the left. The

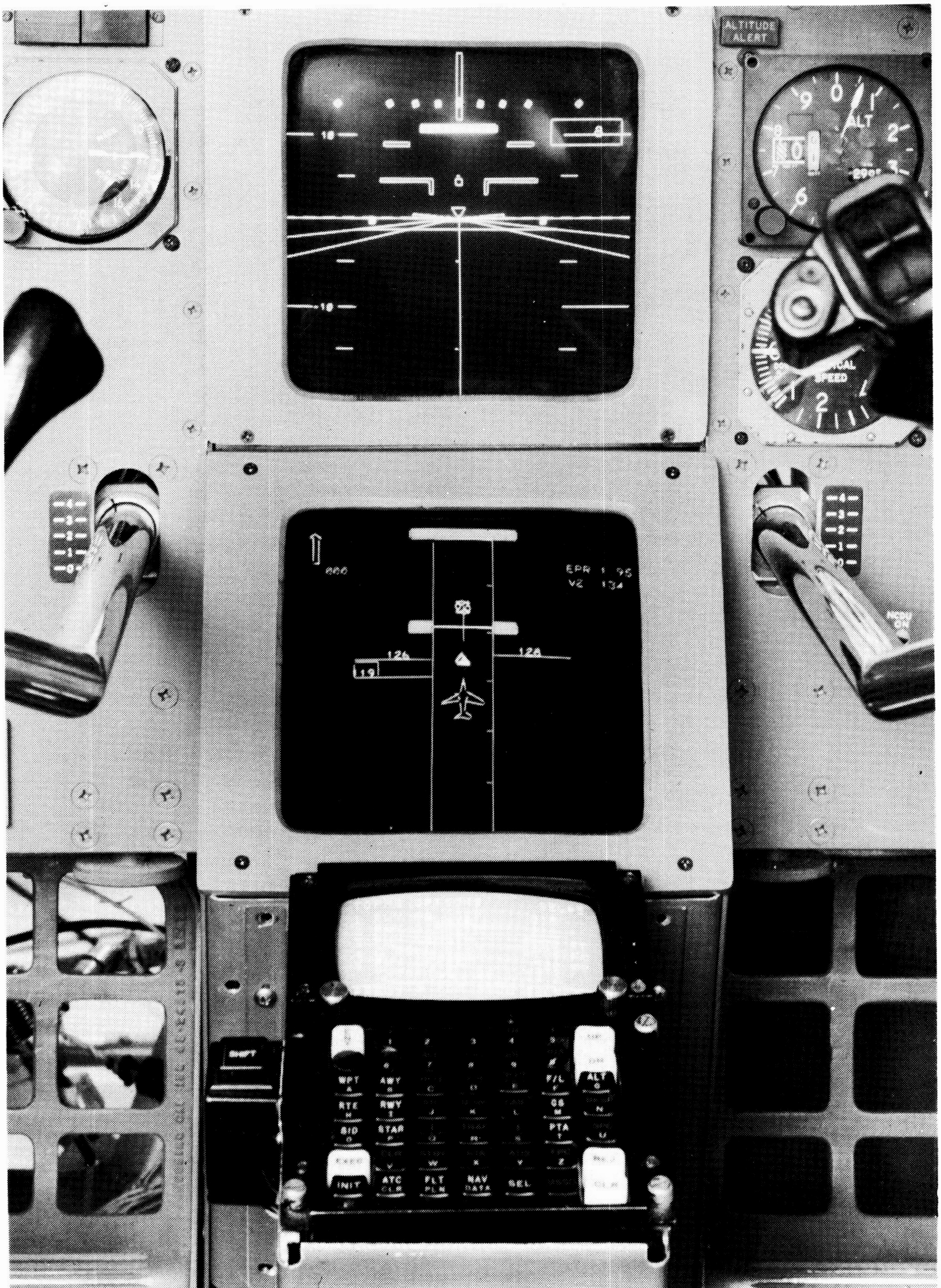

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Figure 3. Primary and Navigation Display screens in TSRV simulator.

box moves down the runway with the airplane symbol. By choice, the airplane symbol does not move laterally. The two triangles indicate where rotation speed V_R will occur; the apex of the open triangle shows the initial or pretakeoff prediction and is thus stationary; the apex of the solid triangle shows the updated position. The V_R line to the right remains aligned with the apex of the solid triangle. The V_1 and V_R lines both track the solid triangle. Just beyond the solid triangle, the ground-roll limit line (GRLL) across the runway represents the farthest location down the runway allowed for reaching V_R; thus for "safe" takeoff, the solid triangle should not cross this line. Engine flags are located (arbitrarily) at each end of the ground-roll limit line. They have two primary states: green for satisfactory operation and red for unsatisfactory operation (i.e., failure). The large rectangle across the end of the runway, labeled "Situation Advisory Flag" provides the pilot with his primary decision advisory information. The TOPMS algorithm analyzes all information pertinent to the takeoff and "summarizes" and presents its findings as particular flag colors—red for "abort" and green for "continue the takeoff." (The flag also has an amber state, which is discussed later in this report.)

Once an abort has been initiated, most of the takeoff-related information is removed from the screen, leaving the display shown in the right side of figure 4. The airplane symbol and the predicted stop point (circled star) for maximum braking remain, but airspeed is replaced with ground speed in the speed box. An additional symbol, shaped like a football, appears to indicate the stop point based on the current measured level of acceleration. In the case shown, less than full braking is being applied.

At the completion of the pretakeoff calculations, the display comes up in a default mode, as shown in the photograph of figure 5. In this mode, the runway length (shown as 4834 feet) has been scaled to the calculated BFL plus a nominal 500-foot offset. (Note that the nose of the airplane symbol is about 500 feet from the starting end of the runway.) Before the takeoff roll begins, the actual offset (or best estimate) and the actual runway length must be entered. The display will adjust accordingly.

The arrow at the top left of the display represents the wind direction (relative to the runway) and the number beside it represents the wind speed in knots. Values for these parameters are input by the pilot. And finally, the recommended engine pressure ratio

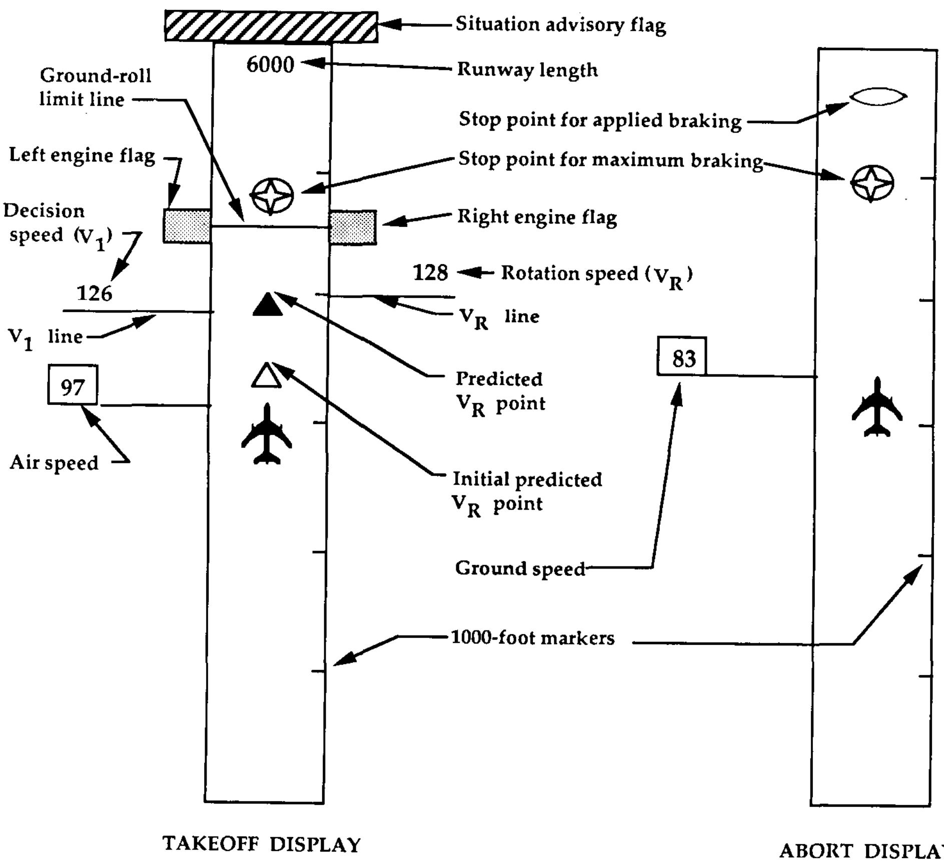

Figure 4. TOPMS takeoff and abort symbology.

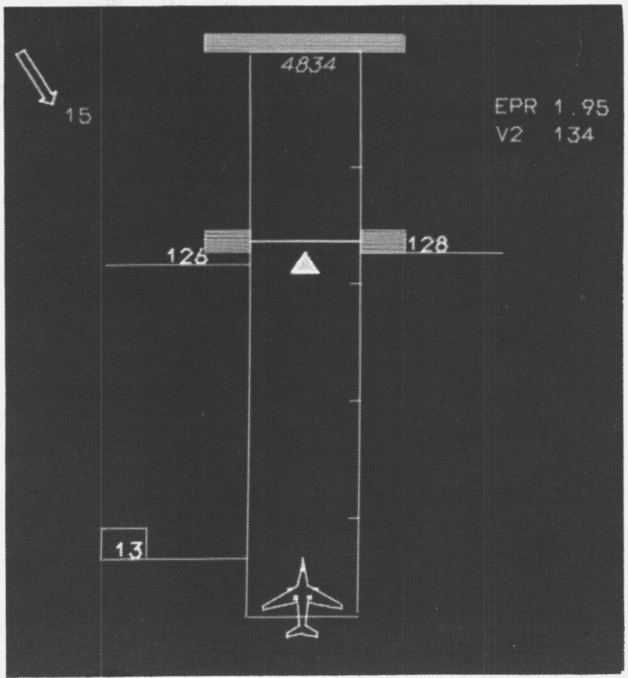

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Figure 5. TOPMS display of balanced field for typical conditions.

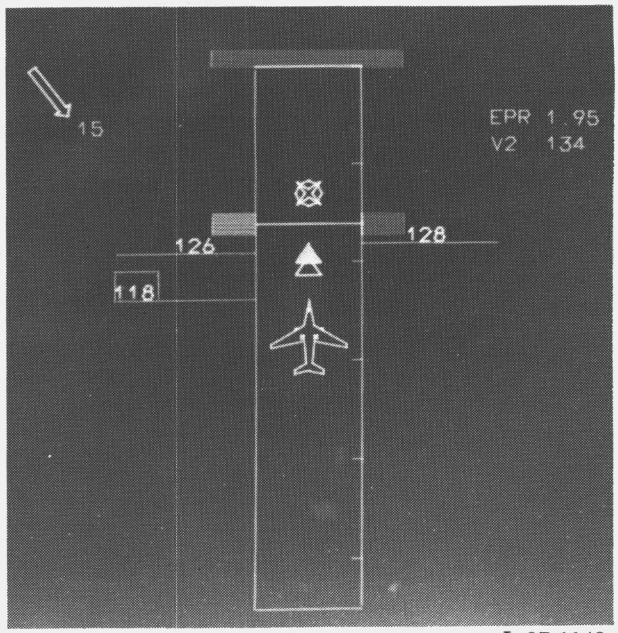

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Figure 6. TOPMS display for engine failure below decision speed V_1.

(EPR) setting (for takeoff) and the second segment climb speed V_2 in knots are shown at the top right corner of the display for reference.

Figure 6 shows a situation with the airplane well into the takeoff run. Calibrated airspeed is 118 knots (shown in speed box to left of the airplane sýmbol). The apex of the open triangle (stationary) represents where the pretakeoff segment predicted V_R will be achieved. The solid triangle and the V_1 and V_R lines have shifted slightly upward (i.e., forward on the runway) from their pretakeoff position and represent the current predictions of where decision speed and rotation speed, respectively, will occur. While not apparent in this black and white photograph, the right-engine flag is red, indicating a failure of the right engine. The situation advisory flag (at the top end of the runway) is also red, indicating that the TOPMS recommends aborting the takeoff run. (Engine failure when airspeed is below decision speed V_1 is postulated in the TOPMS logic as a sufficient condition for abort even though rotation speed V_R can still be reached (note that the solid triangle is still below the GRLL).) A star symbol with a circle around it is seen just beyond the ground-roll limit line. The center of this symbol represents the point on the runway where the airplane will come to a complete stop if abort procedures are initiated from present position and speed, using maximum braking and fully deployed ground spoilers (viz, speed brakes) but no reverse thrust. If there is a delay in initiating the abort, the star will, of course, continue to recede down the runway.

Execution of an abort (initiated by a rapid pull-back of the throttles) causes most of the takeoff information to be removed from the screen, leaving only information pertinent to the abort. Figure 7 shows the display for a typical abort situation. The airplane and the circled star symbols remain. A new symbol (shaped like a football) appears on the display indicating the position where the airplane will stop based on the present level of measured deceleration (in this case, less than full braking). Also, calibrated airspeed is replaced by ground speed in the speed box.

Table 3 summarizes the colors used for the situation advisory flag and the engine flags and their meaning. Table 4 lists the conditions under which the various situation advisory flag colors are used.

Description of TSRV Simulation

The simulated cockpit and instrumentation used in this investigation closely represent those found in the research (aft) flight deck of the Langley Transport Systems Research Vehicle (TSRV). The TSRV is a Boeing 737 class airplane (fig. 8) which has been modified quite extensively (ref. 8) for flight research studies. In particular, the aft flight deck has digital fly-by-wire systems and contains a large complement of CRT displays.

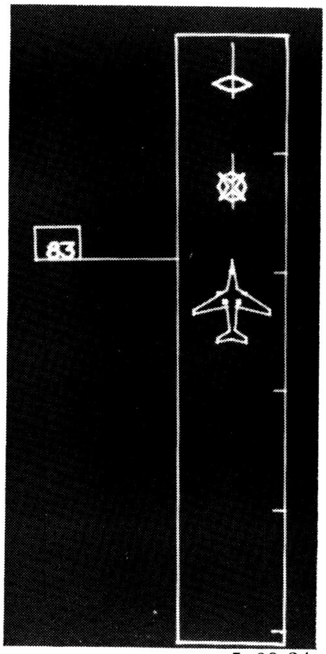

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Figure 7. TOPMS abort display.

Table 3. Flag Colors and Meanings

Situation Advisory Flag

Color	Recommendation
Green	Continue takeoff
Flashing Amber	Continue or abort takeoff (i.e., both options viable)
Red	Abort takeoff

Engine Flag

Color	Meaning
Green	Engine normal
Red	Engine failed

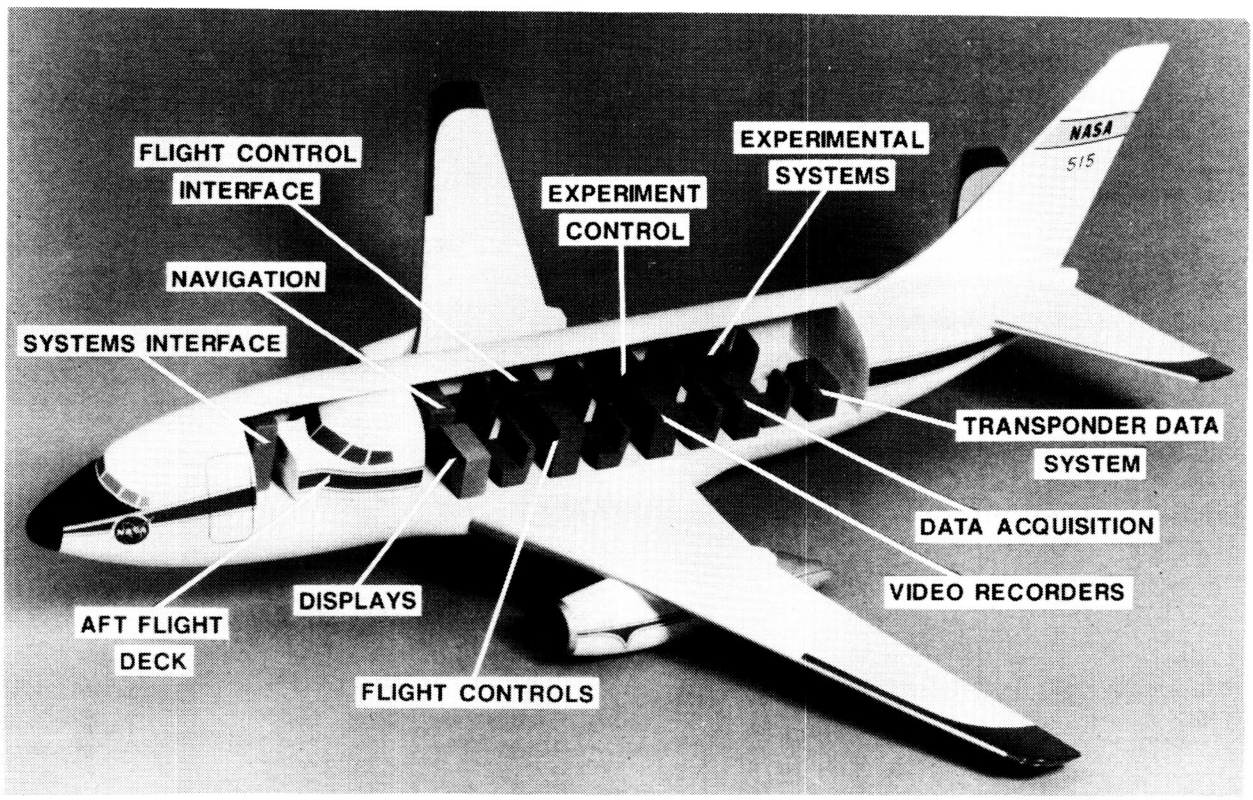

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Figure 8. Cutaway view of Langley TSRV Boeing test airplane.

Table 4. SAF Colors Associated With Various Flight Situations

Flag color	Flight condition
Green	Takeoff is proceeding normally Airplane will attain V_R before it reaches the ground-roll limit line, but it cannot stop within runway distance remaining One engine has failed at a speed equal to or greater than V_1; however, airplane can reach V_R before reaching ground-roll limit line, but it cannot stop within runway distance remaining
Flashing Amber	One engine has failed at a speed equal to or greater than V_1; however, airplane can attain V_R before reaching ground-roll limit line, or it can also stop within runway distance remaining
Red	Predicted rotation point is beyond ground-roll limit line Both engines have failed One engine has failed at speed less than V_1 Longitudinal acceleration is not within specified error band (± 15 percent in this study)

Airplane Model

The TSRV simulation is accomplished with a full six-degree-of-freedom nonlinear model that is made up of a detailed aerodynamic package, an engine model, and a landing gear model. The aerodynamic model incorporates two- and three-dimensional table lookups for aerodynamic coefficients and adjusts these coefficients for ground effects. The engine model includes detailed ram air and temperature effects. The landing gear model includes provisions for braking and for steering.

Research Cockpit

Pilot interface to this simulation model is accomplished through a fixed-base replica of the TSRV research flight deck (fig. 9). It incorporates most of the features found in the actual airplane aft flight deck. The pilot and the copilot each have two CRT displays and a Navigation Control Display Unit (NCDU) arranged in front of them. Unconventional panel-mounted controls (fig. 3), called "Brolley Handles", are split apart and joined behind the instrument panel to allow an unobstructed view of the CRT's. An additional pair of CRT engine displays is located on the center panel. The left CRT shows EPR's, exhaust-gas temperatures, engine speeds, and fuel flow rates as analog tape displays. The right CRT shows these same parameters plus brake temperature and other selected parameters in digital format. The cockpit also has flap, speed brake, and landing gear levers and adjustable rudder pedals with toe brakes at the top.

A Primary Flight Display (PFD) (top screen in fig. 3) is located in front of each pilot. It features attitude, altitude, and airspeed information and incorporates an airplane symbol, a horizon line, bank angle, and pitch attitude markings. The PFD also has symbols for the inertial flight-path angle and commanded flight-path angle. While on the ground, a runway image is superimposed on the display and consists of a centerline and two lines on either side, dividing the runway width into four equal strips. The simulator had no out the window runway view, so this display was used for steering the airplane during takeoff or abort. To the left of the PFD display is the airplane's normal airspeed indicator (electromechanical "round dial"). To the right of the PFD are the airplane's conventional altimeter (top) and the vertical speed indicator.

The CRT below the PFD serves as an ND. This display normally accommodates selected maps and waypoints for guidance and navigation. The TOPMS display appears on this screen when the airplane is on the ground; once main wheel liftoff occurs, the TOPMS display disappears automatically and is replaced by the normal navigation information.

Below the ND is the NCDU. It consists of a small black and white CRT display and an alphanumeric keypad. (See bottom of fig. 3.) This unit is used to enter navigational and other information into the various flight computers; it served as the pilot's pretakeoff input device for TOPMS data.

TOPMS Operation

The Takeoff Performance Monitoring System, as mentioned earlier, is made up of two parts. The first part, the pretakeoff segment, is activated prior to the start of the actual takeoff roll as follows. The pilot, using the NCDU, enters the information listed in table 1 and then initiates the pretakeoff computations.

Once the pretakeoff computations are complete, the ND screen displays a default TOPMS graphic similar to the one shown in figure 5 (for typical conditions). For less typical conditions, such as for

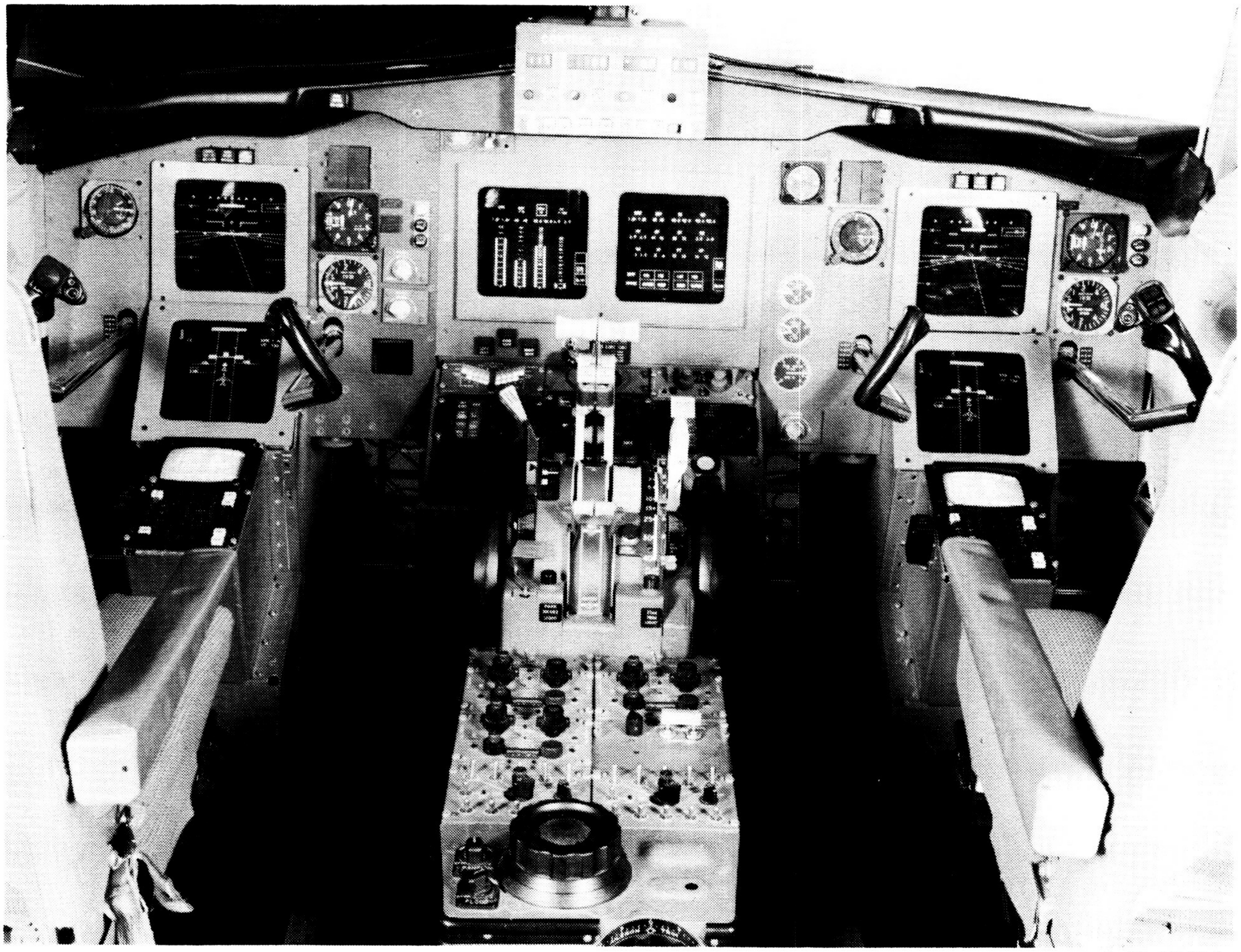

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Figure 9. Cockpit of Langley TSRV Boeing 737 simulator.

high gross weight at a high-altitude airport on a hot day, the display would show a BFL graphic similar to figure 10. After observing the default display, the pilot enters the actual runway length and the display adjusts accordingly. (If runway offset and slope are different from the default values residing in the algorithm, they must also be entered.) The system is now ready for takeoff.

If the entered runway length were less than the calculated BFL plus offset, the display would position the triangles beyond the ground-roll limit line and the situation advisory flag would be red, advising an abort even before the takeoff roll begins. This case is illustrated in figure 11, where the calculated BFL plus offset is 4834 feet and the entered runway length is 4500 feet. If the 500-foot offset were removed (i.e., if the airplane were to begin the takeoff from the threshold), the required field length would reduce to 4334 feet and the triangle would now be below the ground-roll limit line and the situation advisory flag would be green, indicating a takeoff could be attempted.

During the takeoff roll, the pilot flying advances the throttle to an intermediate setting, waits for the EPR to reach an intermediate value (e.g., 1.4) and then moves the throttles to near the recommended takeoff setting (EPR = 1.95); the other pilot makes the final adjustments. (In this study, the runway image on the Primary Display was the visual cue used by the pilots to maintain the airplane on or near the runway centerline.) When rotation speed is reached during a normal takeoff run, the pilot flying pulls on the panel-mounted Brolley Handles and holds them until the airplane pitch attitude reaches about 20°; he then allows the handles to return to neutral. As the wheels lift off the runway, the TOPMS display disappears and is replaced by the standard navigation display. However, if an abort is warranted, the pilot flying pulls the throttles back to idle, deploys the speed brakes (ground spoilers), and applies pressure to the toe brakes (reverse thrust was not used in this study). Accordingly, the takeoff display converts to an abort display similar to the one shown in figure 7.

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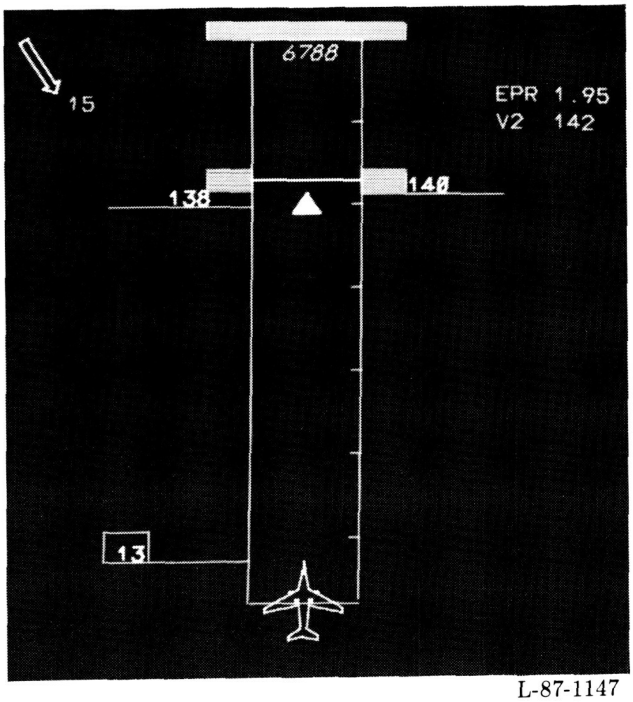

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Figure 10. TOPMS display of a balanced field for heavy airplane on hot day at high-altitude airport.

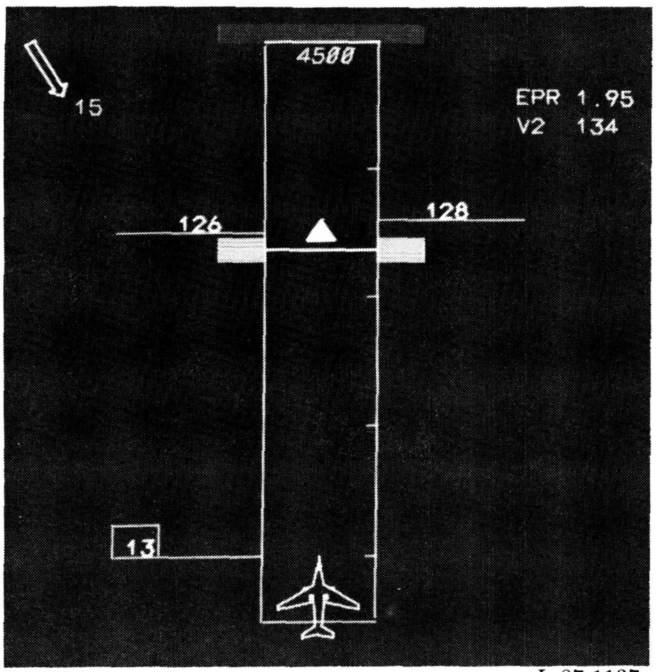

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Figure 11. TOPMS display for runway shorter than balanced field.

Simulator Evaluation

Test Subjects

The TOPMS display was "flown" and evaluated by 32 experienced multiengine-rated pilots on the simulator previously described; 25 of them rated the display using a rating diagram similar to the Cooper-Harper scale of reference 9. The pilot population, shown in table 5, was comprised of Air Force KC-135 tanker pilots, senior pilots from 7 major airlines, research pilots from both government and industry, and several other pilots (e.g., retired, National Guard).

Test Procedures and Conditions

The real-time simulation sessions each involved two pilots working as a crew. Most had not met or worked together before. The subject pairs received a short advance writeup (see appendix A) and were shown a 10-minute video on the system before proceeding to execute a program of takeoffs and/or aborts while monitoring the TOPMS display. After several practice runs, each pilot flew for approximately 2 hours—1 hour as the pilot flying and 1 hour as the pilot not flying. During the practice runs, the crews agreed on their division of duties and operating procedures (e.g., what speeds or events the pilot not flying would call out to the pilot flying). The program itself consisted of approximately 20 runs for each pilot, covering a variety of conditions including normal takeoffs; reduced-thrust takeoffs; several gross weights, temperatures (0°–100°F), pressure altitudes (0–5000 ft), and headwind-crosswind conditions; several runway lengths, offsets, and surfaces (e.g., dry, wet, icy); engine failures; and unannounced deployment of spoilers (to create acceleration anomalies). As a minimum, each pilot saw all the conditions listed in table 4. The runs were not presented in any specific order and the pilots did not know when a failure situation would occur. However, the first few runs were usually normal takeoffs with temperature or wind variations to allow the pilots to gain additional familiarity with the simulation before having to perform an abort.

At the conclusion of the simulation session, each pilot was asked to independently evaluate the system by (1) making unsolicited comments, (2) answering specific questions (see appendix B), and (3) giving a "goodness" rating for the TOPMS display, according to the scale shown in appendix B. The rating scale (1–10) was patterned after the diagram/scale associated with the Cooper-Harper scale (ref. 9) for aircraft handling qualities. The numerical ratings of the TOPMS displays were averaged overall and by pilot group.

The pilots were instructed (in writing and verbally) not to let factors such as unfamiliar controls and cockpit displays and arrangements or the location of the TOPMS display with respect to these other displays influence their rating of the TOPMS per se. (The pilots were, however, encouraged to

Table 5. TOPMS Evaluation Pilots

Categories	Number of pilots	Average flying hours
Air Force	7	3 600
Airline	9	16 500
Delta		
Eastern		
Northwest		
Pan Am		
Piedmont		
TWA		
United		
Research	12	5 900
NASA/FAA		
Boeing		
Lockheed		
McDonnell Douglas		
Other	4	5 200
Total	32	8 300

identify desirable and undesirable features of the overall simulation).

Example Test Runs

In addition to normal takeoffs and the engine-out case shown in figure 6, the test runs included reduced-thrust takeoffs, mandatory takeoffs (with one or two good engines) because the predicted stop point was beyond the end of the runway, the (pilot's) choice of takeoff or abort (on a long runway) because of engine failure at V_1, and aborts due to deficient acceleration relative to the nominal value associated with the selected throttle setting. Several such runs are shown and discussed in the following paragraphs.

Figure 12 shows the TOPMS display for a reduced-thrust takeoff. The throttles were set low, resulting in an EPR of about 1.80 instead of the recommended 1.95 value (shown at the upper right of the photograph and used in the pretakeoff calculations). The salient cues are (1) the separated triangles, indicating that acceleration has been below nominal and, consequently, the distance to reach V_R has been lengthened and (2) the continued-green engine and situation advisory flags, indicating that the engines are operating properly for the throttle setting being used. The airplane has reached 97 knots and is predicted to reach V_1 (and V_R) before the solid triangle reaches the ground-roll limit line. A satisfactory takeoff is thus expected.

Figure 13 shows a situation where airspeed has exceeded V_R and the stop star has advanced past

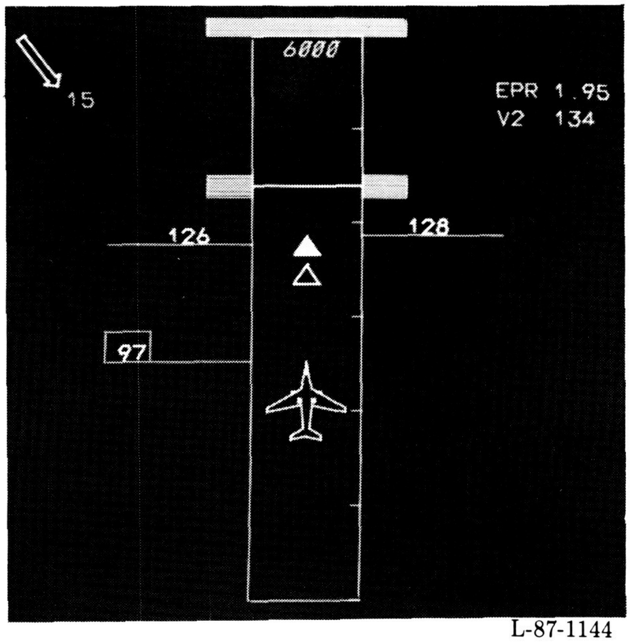

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Figure 12. TOPMS display during a reduced-thrust takeoff.

the end of the runway (and is blinking), thus signalling loss of the stop option. The information is primarily academic at this point because the takeoff roll has been normal (i.e., no acceleration or thrust deficiencies have occurred) and rotation is actually underway.

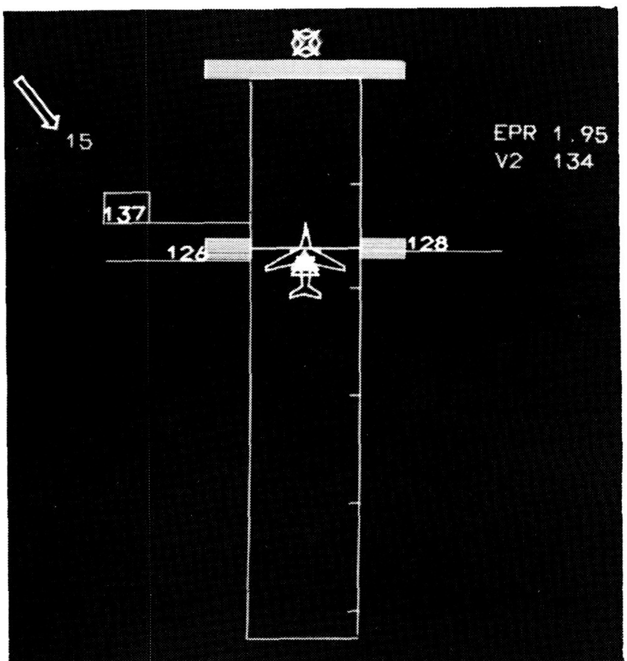

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Figure 13. TOPMS display showing stop point beyond end of runway.

Figure 14 shows a similar situation except an engine has just failed. Again, the takeoff must continue because (1) physically the stop option is gone and (2) Federal Aviation Regulations (FAR—Part 25 (ref. 7)) require takeoff, go around and reland when the failure occurs at a speed equal to or greater than V_1.

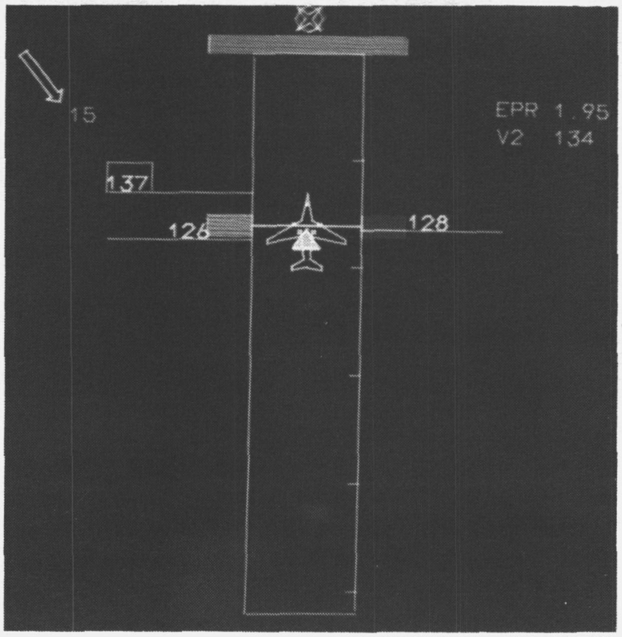

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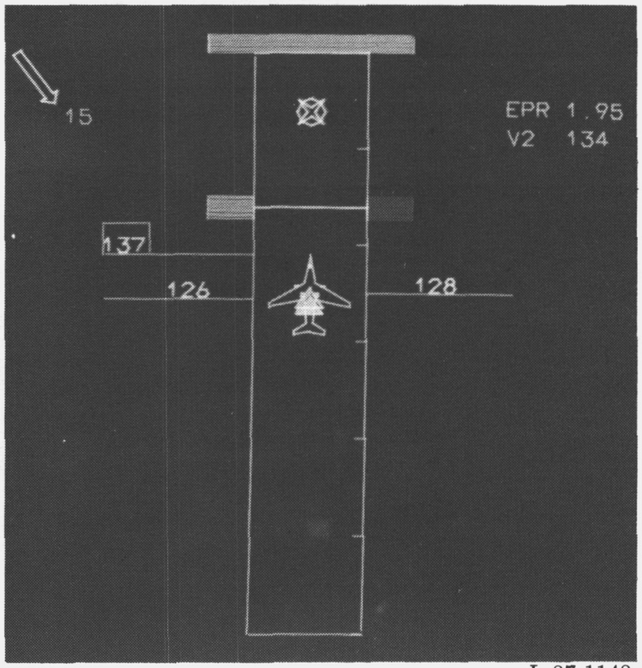
Figure 14. TOPMS display for engine failure with stop point beyond end of runway.

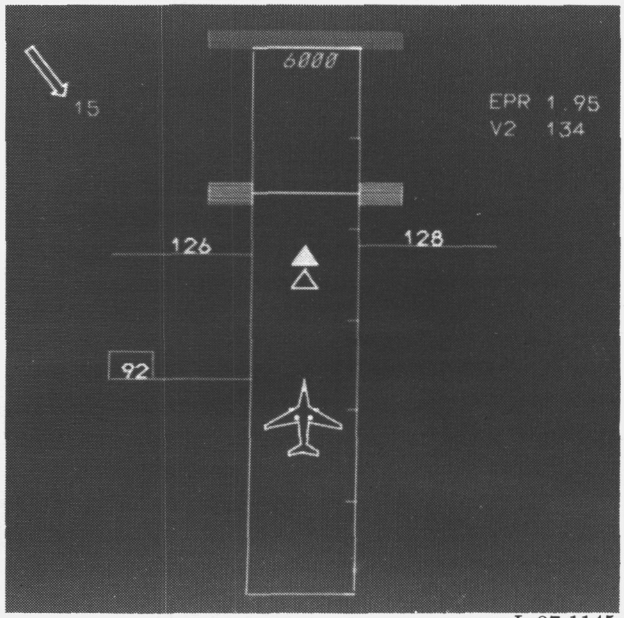
Figure 15 also shows an engine loss at a speed greater than V_1, but the stop star is still on the runway and the situation advisory flag is amber (and blinking), indicating that the stop option is still physically available; however, the pilot will most likely opt to continue the takeoff because of the FAR requirement to continue and because a maximum-effort high-speed abort would be rather risky (due to brake heating and the small stop-margin remaining). However, in a similar circumstance on a much longer runway, the pilot might consider an abort if, for example, a fire had been detected.

Figure 16 shows a situation where there is no engine failure (engine flags are both green), but an abort is recommended (situation advisory flag is red). The measured EPR (not shown) is at the recommended 1.95 level, but the triangles have separated indicating that the sampled accelerations differ significantly from the nominal values (calculated by algorithm) because of excess drag (or because the wheels may be running in slush or water). (This picture was set up by deploying the spoilers to create excess drag.) This case differs from that of figure 12 in that the throttles were set at the recommended level and the lower acceleration is a deficiency rather than just a lower level associated with a lower throttle setting. The TOPMS logic is designed to recommend an abort whenever the deficiency exceeds 15 percent or some other selected value. In the case shown in figure 16, it appears that the airplane can still reach V_R before reaching the ground-roll limit line; however, the situation will worsen quickly as the drag



L-87-1148

Figure 15. TOPMS display for engine failure above decision speed with stop point still on runway.



L-87-1145

Figure 16. TOPMS display for acceleration failure not related to engine performance.

increases with speed. Consequently, an abort is in order.

Other cases not shown involved combinations of high and low temperature, pressure altitude, and gross weight. Several pilots requested and were given conditions not on the list of 20 scheduled runs, and whenever time permitted, all were allowed to repeat particular runs if they felt they may have missed some information as it evolved during their initial run.

Results

As indicated above, two types of results were obtained: (1) solicited and unsolicited comments and (2) display ratings. The solicited comments were primarily answers to two sets of guideline questions, one supporting the rating scale and the other asking how such a system would be used and/or accepted by the pilot and his preference for particular elements or symbols in the display. The rating scale and questions (see appendix C) were based on criteria related to the appropriateness for the task and how easy or difficult it was to extract and comprehend the data, particularly during a relatively quick scan. Other criteria included credibility, compatibility with other cockpit information, and effect on mental effort when this display is integrated with existing cockpit instrumentation.

Pilot Opinions and Comments

In general, the pilots were impressed with the features of the TOPMS and would like to see TOPMS-type information in their cockpit. There was a variety of opinions on how the TOPMS would enhance or distract the pilot from his "normal" takeoff duties or scan pattern. Some thought that adding a TOPMS display might add slightly to presently defined procedures and current scan patterns, but others thought that it might eliminate some subtasks or reduce the number of times certain elements had to be performed. However, there was a consensus that it would provide the crew with valuable information currently not available in the cockpit.

Particular comments offered by the evaluation pilots include

1. The pilot flying should be looking out of the window during most of the takeoff; therefore, the pilot not flying should have prime responsibility for monitoring the TOPMS. However, the pilot flying should have a duplicate of this display available for reference, and in addition, he would like to have a simplified head-up version available in the vicinity of his windshield.

2. The pilots indicated a strong need and desire for the following information/symbology that was provided on the TOPMS display:

    Visual indication of the limit of allowable ground roll for reaching V_R (viz, the line across the runway graphic between the engine flags)

    Pictorial and numeric indication of the balanced field length

    Expected locations (symbol and lines) where V_1 and V_R will be reached (also the visual increment between these locations and the ground-roll limit line)

    Improved analog indication of the difference between the current airspeed of the airplane and V_1 (or V_R); this dynamic cue is manifested by both the amount of separation between the CAS and V_1 lines and their perceived closure rate (this same information is available on most dial-type airspeed instruments, but is not nearly as easy to monitor)

    Expected location (symbol) where the airplane can be braked to a stop from its current location and speed

    Graphic indication of the current position of the airplane and the speed with respect to the 1000-foot markers on the side of the runway, as well as to the above references

    Situation advisory flag, which summarizes all the takeoff-related information into a single source and recommends a course of action

    Right and left engine-failure flags

    These items are not prioritized. The symbology and colors used to impart this information were judged to be satisfactory and intuitively easy to understand.

3. The pilots would prefer that the TOPMS be located higher on the instrument panel, even if a head-up TOPMS were also available. The large scan angle from the windshield to the Navigation Display screen location was considered undesirable, but acceptable.

4. Several pilots suggested that the TOPMS airplane symbol be driven in the lateral plane; however, most considered such an implementation to be undesirable because of the potential temptation to use the TOPMS display for lateral-directional control during the takeoff or abort task.

5. The pilots also agreed (unanimously) that conversion from the Takeoff Display to the relatively simple Abort Display was quite desirable and that the transition occurred transparently.

6. The pilots would like to see the Abort Display adapted to landing rollout and braking.

The most frequent suggestions for TOPMS modification were to add the head-up display (HUD) and to be more conservative in the logic governing the amber-flashing mode of the situation advisory flag (viz, "Don't suggest the *stop option* to the pilot when $V \geq V_1$ unless there is a generous safety margin in the predicted stop distance)." Other pilot suggestions covered miscellaneous preferences and additions such as auditory cues and/or alphanumeric message windows. All these comments are being considered in a revision of the TOPMS which will be checked out in the simulator before being flight tested.

Pilot Ratings of Display

Twenty-five of the 32 invited multiengine-rated pilots gave the TOPMS a numerical rating derived from the flow diagram/scale shown in appendix C. The ratings obtained ranged from 1 to 5, according to the distribution shown in figure 17. The pilots were grouped according to their current occupation as (1) Air Force (primarily four-engine tanker crews), (2) commercial airline pilots, (3) government and industry research test pilots, and (4) other. The average ratings by job-experience group are shown in figure 18. The average rating given by the 25 pilots was 2.92, where 3 corresponds to "satisfactory—good."

No direct correlation was found between rating value and total hours of flying experience. The Air Force pilots as a group had the least average number of flying hours (3600) and the commercial pilots the most (16 500). The Air Force pilots, however, had more takeoffs per hundred flying hours. The rating was a convenient way of quantifying the pilot's opinion of the value or merits of the display, but it should not be separated from the comments that accompanied it. For example, some pilots cited multiple annoyances and gave several suggestions for modification, yet rated the system "2—very good" because the information obtained from the display was considered potentially quite valuable from a safety

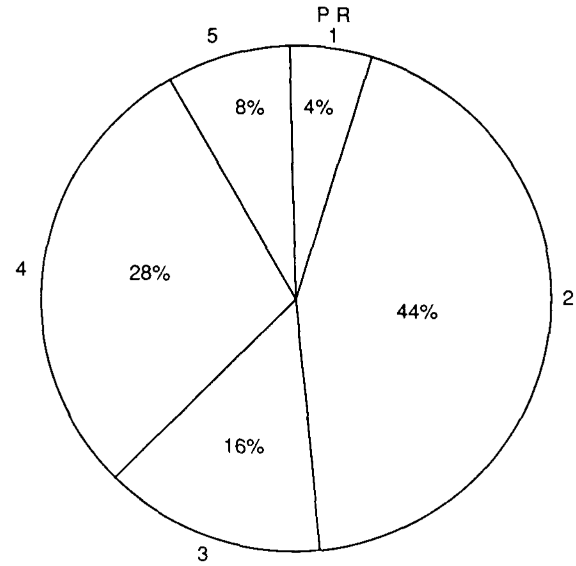


Figure 17. Distribution of pilot ratings. PR = Pilot rating (on 1–10 scale).

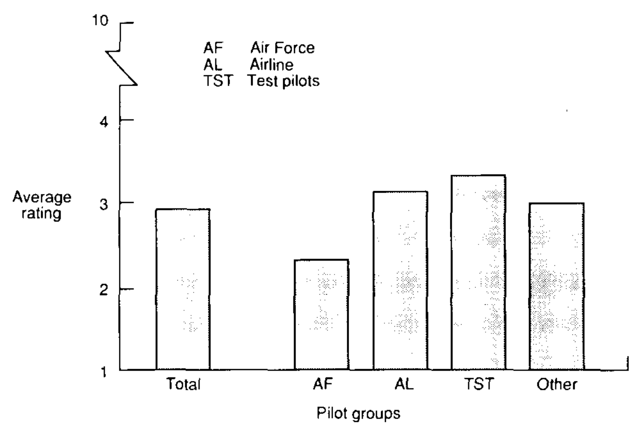


Figure 18. Ratings by pilot group.

standpoint. Other pilots praised the system, but rated it a 4 or 5 because of a single deficiency that they felt needed to be corrected. In several cases, the identified deficiency was related more to simulation artifacts (e.g., location of the display in the cockpit) than to the TOPMS algorithm/display. Further, these pilots indicated that the criteria listed for ratings of 1, 2, or 3 in the rating diagram did not seem to allow for any deficiencies (i.e., it had no words to that effect); therefore they gave a rating of 4 because such a rating allowed for "minor deficiencies".

Concluding Remarks

The display evaluated in this study provides the first indication of how pilots might accept and use the status, progress, and advisory information generated by the Takeoff Performance Monitoring System (TOPMS) algorithm. The display was well received by 32 experienced pilots, and all encouraged its continued development. It was considered a valuable, easy-to-use safety aid. In particular, they said that in the location where it was tested, it should require no more than scan monitoring by the pilot making the takeoff; if it was also implemented in a head-up configuration/location, he could and would effortlessly glean additional information from it. They further said that with or without the head-up display, the pilot not flying should be given primary responsibility for monitoring the head-down TOPMS display and announcing pertinent events and/or advisories to the pilot flying. Once an abort was underway, it was speculated that the head-up configuration would be particularly useful in interactively determining the level of braking needed to stop the airplane at a desired location (e.g., near an exit ramp).

It is recommended that a head-up TOPMS display incorporating several refinements suggested by the pilots be developed and evaluated on the same simulator. Also, a selected TOPMS head-down configuration should be implemented and tested on the Langley Boeing 737 research airplane. For consistency, the rating diagram used in the present study should not be revised for either of these studies; however, it appears that some improvement to the wording of the criteria can and should be made before it is used in future studies.

NASA Langley Research Center
Hampton, VA 23665-5225
March 23, 1989

References

1. Minutes of Meeting #1 of the Take-Off Performance Monitoring Ad Hoc Committee. Aircraft Div., Aerospace Council, Soc. of Automotive Engineers, Inc. (Washington, D.C.), May 15 & 16, 1984.
2. Small, John T., Jr.: Feasibility of Using Longitudinal Acceleration (N_x) for Monitoring Takeoff and Stopping Performance From the Cockpit. *The 1983 Report to the Aerospace Profession—27th Symposium Proceedings,* vol. 18, no. 4, Soc. of Experimental Test Pilots, c.1983, pp. 143–154.
3. Boeing Co. (Patrick J. Cleary, Lloyd S. Kelman, and Richard L. Horn): Aircraft Performance Margin Indicator. European Patent Appl. No. 85200977.8, Publ. No. 0 166 487 A2, June 19, 1985.
4. Srivatsan, R.; Downing, David R.; and Bryant, Wayne H.: *Development of a Takeoff Performance Monitoring System.* NASA TM-89001, 1986.
5. Srivatsan, Raghavachari: Design of a Takeoff Performance Monitoring System. DE Diss., Univ. of Kansas, 1985.
6. Srivatsan, Raghavachari; and Downing, David R.: *Development of a Takeoff Performance Monitoring System.* NASA CR-178255, 1987.
7. *Airworthiness Standards: Transport Category Airplanes.* FAR Pt. 25, Federal Aviation Adm., June 1974.
8. Staff of NASA Langley Research Center and Boeing Commercial Airplane Company: *Terminal Configured Vehicle Program—Test Facilities Guide.* NASA SP-435, 1980.
9. Cooper, George E.; and Harper, Robert P., Jr.: *The Use of Pilot Rating in Evaluation of Aircraft Handling Qualities.* NASA TN D-5153, 1969.

Appendix A

Pilot Information Package

1. PURPOSE OF THE TOPMS - To provide guideline information to the pilot(s) for making decisions concerning takeoffs and aborts.

2. PILOTING OBJECTIVE/TASK - To control the TSRV airplane during takeoff, to decide IF/WHEN to abort, and to perform the abort if required.

3. SIMULATION OBJECTIVES -
   a. Primary - To qualitatively (and quantitatively) evaluate the TOPMS. (viz, to solicit pilot comments/suggestions on existing features and modifications (if any) prior to implementing the hardware/software on the TSRV airplane; also to rate the TOPMS displays using the rating chart and criteria provided. [See Appendix B]
   b. Secondary - To obtain representative groundroll, liftoff, etc. data.

4. TOPMS ALGORITHM - Calculates a predicted performance based on:
   a. Ambient temperature
   b. Pressure altitude
   c. Winds: speed and direction
   d. Gross weight/c.g. location
   e. Flap setting
   f. Rolling/braking friction coefficient
   g. Runway length/direction & "offset"(starting position)
   h. Airplane's updated position, velocity, and acceleration

5. DATA INPUT/OUTPUT - The above information is entered into the flight computer through the Nav. & Control Display Unit (NCDU) and/or by sensors. The TOPMS algorithm then makes a "pretakeoff" prediction of:
   a. Distance down the runway where V_1 and V_R will occur
   b. Balanced Field Length (BFL) - (defined on next page)
   c. Groundroll limit to reach V_R
   d. Normal or reduced-thrust throttle/EPR settings

   In real-time, the algorithm updates (a) above and also continually predicts a brake-to-a-stop point based on maximum wheel braking and full ground-spoiler deployment. In the ABORT mode it additionally predicts a stop point based on actual braking/deceleration conditions (including reverse thrust).

6. TOPMS DISPLAYS - The takeoff/abort advisory information generated and output by the TOPMS algorithm is presented to the pilots on CRT-type display screens located on the cockpit instrument panel (see sketch on third page).

ORIGINAL PAGE IS
OF POOR QUALITY

HEAD-DOWN TOPMS DISPLAY: INTERPRETATION OF FUNCTIONS/SYMBOLOGY

RUNWAY LENGTH - Pilot enters value (in ft) for the local airport; this value is then displayed digitally at far end of the runway graphic and sizes the graphic to the full height of the CRT display screen. Initially, BALANCED FIELD LENGTH(BFL) appears as a default runway-length value; BFL is defined as the GROUNDROLL DISTANCE (required to reach V_1) plus the greater of:
(1) the braking (wheels + spoilers) distance to stop from V_1,
(2) or the ground distance between V_1 & V_R combined with the air distance required to rotate & clear a height of 35 ft. at the end of the runway with one engine failed.

AIRPLANE SYMBOL - Tip of airplane nose indicates present longitudinal position of the airplane on the runway.

DIGITAL No. in BOX (extending from nose of airplane symbol) - Gives current airspeed (CAS) in kts; (Box(es) & No.(s) advance with airplane)

SOLID TRIANGLE(▲) - Apex indicates longitudinal position on the runway where the airplane will reach an airspeed (CAS) of V_R.
- Digital No. to right of (▲) indicates V_R in knots
- " " " left " " " V_1 " "

(Note: Both the No's & lines move with (▲) as it is updated.)

OPEN TRIANGLE (△) - Indicates initial position of solid triangle. Note that THIS TRIANGLE DOES NOT MOVE; it is for reference only!

ENGINE-OUT FLAGS - Will turn from GREEN to RED when the engine "fails". (e.g., when EPR < 85 % of value "commanded" by throttle)

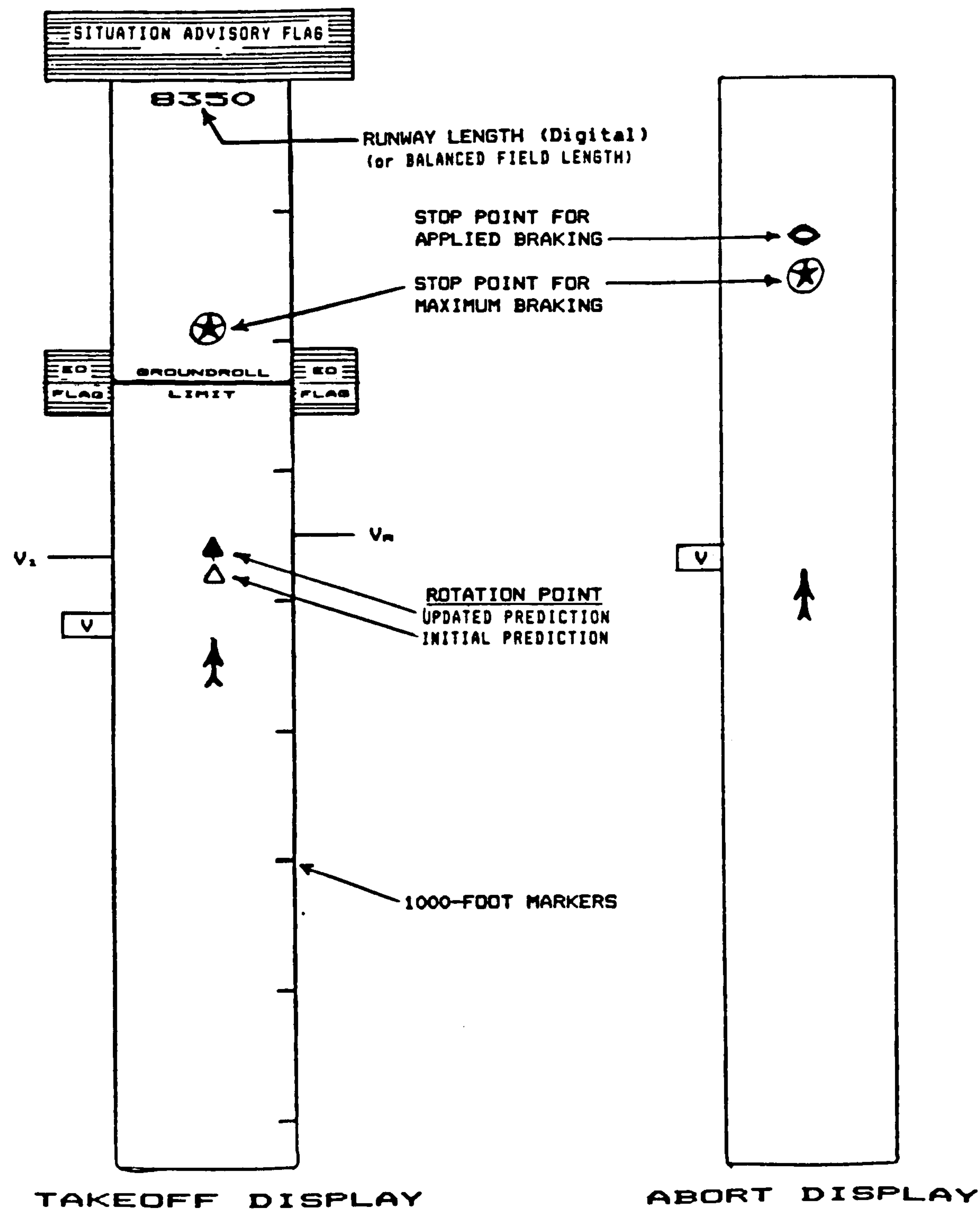
LINE BETWEEN E.O. FLAGS - Marks limit of the GROUNDROLL DISTANCE to V_R for clearing a 35-foot fence with one engine failed; this line repositioned automatically whenever a new value for RUNWAY LENGTH is entered through the NCDU.

SITUATION ADVISORY FLAG - Rectangle (RED/AMBER/or GREEN) at end of runway symbol.

STOP-STAR - Indicates where the airplane can be braked to a stop from current conditions (using maximum wheel and spoiler braking, but no reverse thrust). The STAR does not appear on the display until the predicted stop point is beyond the GROUNDROLL LIMIT LINE; when the STAR reaches the end of the runway, it blinks to alert the pilot that he no longer has the option to abort.

FOOTBALL - Indicates stop point if current level (i.e., measured) of deceleration is continued (affected by both braking & reverse thrust).

WHEN ABORT INITIATED, TAKEOFF DISPLAY CONVERTS TO ABORT DISPLAY (see fig.).


SITUATION ADVISORY FLAG
8350
RUNWAY LENGTH (Digital)
(or BALANCED FIELD LENGTH)
STOP POINT FOR
APPLIED BRAKING
STOP POINT FOR
MAXIMUM BRAKING
EO FLAG
GROUNDROLL LIMIT
EO FLAG
V
V
ROTATION POINT
UPDATED PREDICTION
INITIAL PREDICTION
V
V
1000-FOOT MARKERS
TAKEOFF DISPLAY
ABORT DISPLAY

FLAG CONDITIONS FOR SITUATION ADVISORY FLAG (SAF)

RED

1. Airplane will not reach "Rotational Speed"(V_R) within the groundroll distance allowed (i.e., without first reaching the GROUNDROLL-LIMIT LINE, beyond which the airplane may not be able to rotate and clear a 35' obstacle at the end of the runway with one engine failed.)

2. Performance failure detected (viz., measured along-track acceleration is not within ±15% of that expected for the throttle setting being used).[1]

3. One engine fails when Airspeed (CAS) is less than V_1 ("Decision Speed").

4. Both engines fail.

AMBER - Blinking

5. One engine fails when airspeed is greater than V_1 ; however.........
   * Airplane can reach V_R before reaching the GROUNDROLL LIMIT LINE,
   * AND there is ample runway still available for braking-to-a-stop.[2]
   (Note - Braking involves wheels/spoilers only, no credit is taken for reverse thrust.)

GREEN

6. One engine fails when airspeed is greater than V_1 ; however...........
   * Airplane can reach V_R before reaching the GROUNDROLL LIMIT LINE,
   * ...BUT... there is NOT ample runway still available for braking-to-a-stop.[2]

7. Normal Takeoff --- Everything appears to be proceeding O.K.!!!

Notes: [1] The ±15% acceleration deviation (from "nominal") was selected in this study as the threshold for an "Acceleration Performance Failure"; another value can be used just as well.

[2] "ample runway distance available for braking-to-a-stop" includes computed distance requirement for dry asphalt.

PILOT RATING INSTRUCTIONS

The primary interest in having adjectives and numerical values associated with the TAKEOFF PERFORMANCE MONITORING SYSTEM (TOPMS) is to help establish the "goodness" of the TOPMS algorithm as manifested by the display. As the pilot evaluator, you are asked to judge the display, per se, with secondary consideration being given to size, location, and integration with other information sources. These secondary factors should, however, be identified and mentioned in your comments and answers to the debriefing questions. [Appendix C]

The TOPMS implementation that you will be seeing on the TSRV B-737 simulator represents the setup for testing it on the TSRV airplane itself. In particular, it will be tested in the aft flight deck, which has no outside view; thus, no simulated out-the-window view is provided for the simulation. Guidance cues for steering the airplane along the runway centerline will be superimposed on the EADI instrument just above the TOPMS display. Therefore, your rating of the TOPMS should not be influenced by what you see on the EADI; it is not a part of the evaluation.

The TOPMS rating diagram [see Appendix B] included in this package is patterned after the Revised Cooper-Harper Rating Scale for aircraft handling qualities. The evaluator should enter it from the bottom left and proceed upward and/or to the right. The associated questionnaire [Appendix B] is designed to flow accordingly, and should assist you in determining which criteria are met. It is requested that the rating diagram and questionnaire be explored jointly before any rating is made; then on a second pass through the diagram, the appropriate rating should be selected.

[The debriefing questions (Appendix C) were not given to the evaluation pilots; however, the rating diagram and associated questionnaire (Appendix B) were included in the prebriefing package sent to them.

Photographs of the TSRV airplane and aft flight deck were included in the prebriefing package. They are deleted from this appendix because they are similar to figures 5 and 6.]

Appendix B

Pilot Evaluation Questionnaire and Rating Diagram

1. Is the system "USABLE", and does it support the task? (Y/N?)
   If not, WHY NOT?

2. If so, then is it "ACCEPTABLE" as configured/implemented? (Y/N?)

   a. Is the information adequate and suitable for the task(s) being performed?

   b. Is the display believable; that is, does it clearly relate the dynamic situation to the pilot and complement his comprehension of the situation?
      - Is it free of contradiction within itself?
      - Does information on the display agree with similar type information obtained from other instruments, etc.

   c. Are the quality and dynamics of the display tolerable (even though it may contain some annoyances/deficiencies?

   d. Does the monitoring task require no more than a moderate mental workload?

3. If the system, as implemented, is considered "UNACCEPTABLE", skip to Question 7; otherwise, continue.

4. Is the system "SATISFACTORY", requiring no significant modification? (If not, skip to Question 6) (Y/N?)

   a. Is the displayed information adequate, and well suited for the task?

   b. Does the display have good clarity? resolution? contrast? and dynamics (e.g., is it free of annoyances such as lag, stepping, smearing, flicker etc.)?

   c. Does the monitoring task require low mental effort?

5. Go to Question 8, and continue.

6. From Q4......What IMPROVEMENTS ARE WARRANTED? That is, what can or should be changed to make the system SATISFACTORY? In particular:

   a. What elements or combinations of elements contain:
      - Minor deficiencies? What are they?
      - Moderate deficiencies? " " "
      - Major deficiencies? " " "

   b. Which deficiencies, if any, are considered to be somewhat annoying but do not lead to confusion, decreased comprehension or degraded performance?

   c. Which deficiencies should be corrected in order to:
      - Eliminate significant annoyances (and reduce mental workload)?
      - Increase the ease of comprehension and/or the ease of monitoring the display?

   d. Skip to Question 8 and continue.

7. From Q3, page 1.........What makes the system "UNACCEPTABLE"?

   a. Poor input information (or lack of good info) from algorithm?
      - Desirable information missing or presented inappropriately?
      - Excessive or irrelevant information?
      - Redundant information that is distracting/not helpful?

   b. Display format?
      - Poor choice and/or placement of symbols/alpha-numerics?
      - Unrealistic size/movement of symbols?
      - Inappropriate appearance/disappearance of certain cues?
      - Confusing mixture of graphics and digital information?
      - Other?

   c. Display credibility?
      - What factors affect the credibility? Is more than one parameter or feature involved?
      - Would a different choice of graphics enhance the credibility? Or does any credibility problem lie with the input information?
      - In what respects does the displayed information conflict with concurrent information obtained from other sources?
      - Other factors?

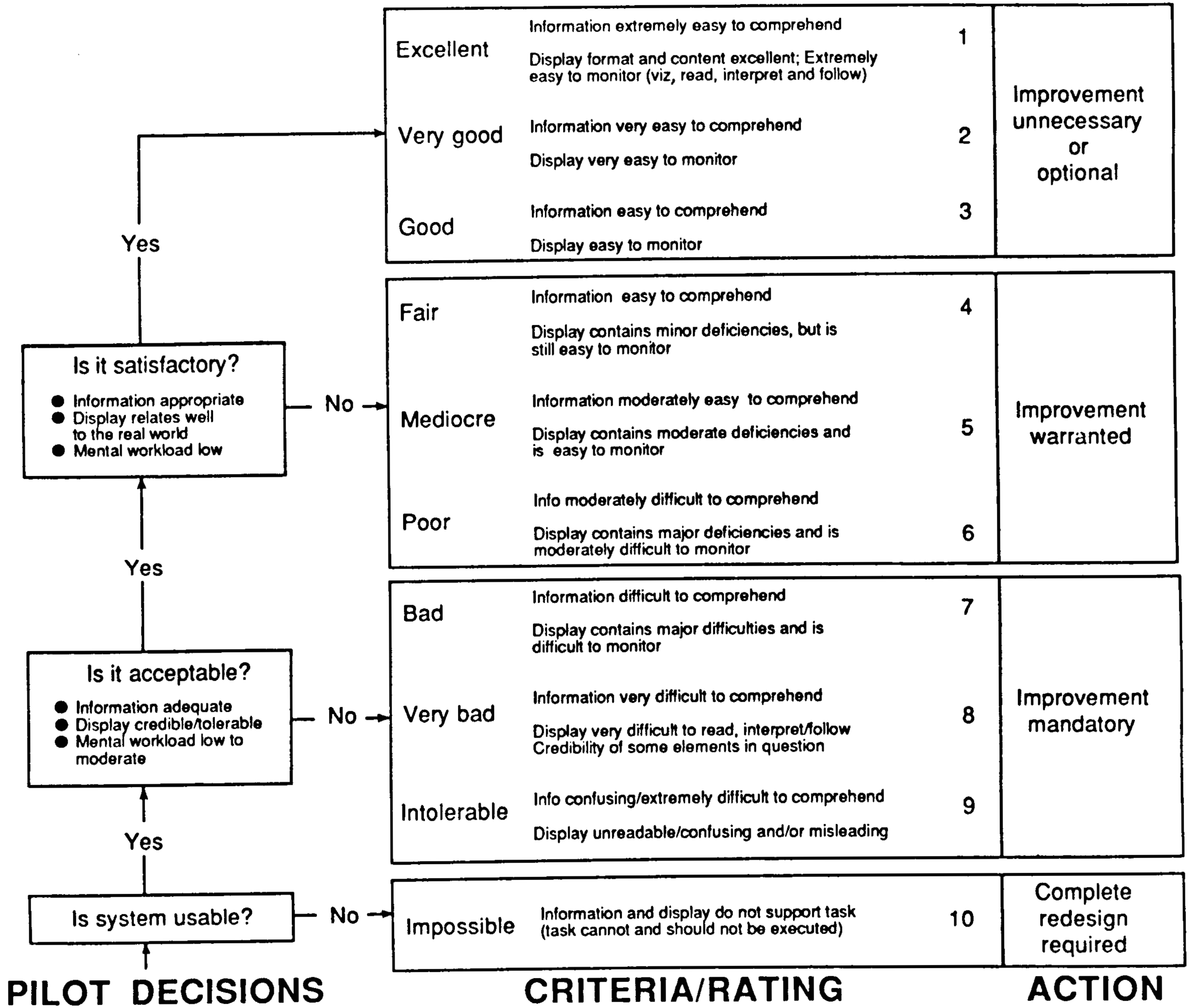
   d. Mental workload / intensity of concentration
      - High?
      - Tolerable?

e. Other:
   - Display quality (resolution, contrast, scaling, etc.)?
   - Interpretation, readability, and followability of display?
   - Location of display? Would it be ACCEPTABLE in another location?

8. From Q5, page 1.....What changes would you recommend in the following?
   a. Input information?
   b. Display format and/or symbolism? Size? Contrast?
   c. Display dynamics?
   d. Location in cockpit?

9. Are these recommendations, if any, suggestions for improvement of the existing system,or are they investigative alternatives?

10. END - (Use the above questions in conjunction with the rating diagram that appears on the following page.)



Is system usable?
Yes
No
Is it acceptable?
Information adequate
Display credible/tolerable
Mental workload low to moderate
Yes
No
Is it satisfactory?
Information appropriate
Display relates well to the real world
Mental workload low
Yes
No
Excellent
Information extremely easy to comprehend
Display format and content excellent; Extremely easy to monitor (viz, read, interpret and follow)
1
Very good
Information very easy to comprehend
Display very easy to monitor
2
Good
Information easy to comprehend
Display easy to monitor
3
Improvement unnecessary or optional
Fair
Information easy to comprehend
Display contains minor deficiencies, but is still easy to monitor
4
Mediocre
Information moderately easy to comprehend
Display contains moderate deficiencies and is easy to monitor
5
Poor
Info moderately difficult to comprehend
Display contains major deficiencies and is moderately difficult to monitor
6
Improvement warranted
Bad
Information difficult to comprehend
Display contains major difficulties and is difficult to monitor
7
Very bad
Information very difficult to comprehend
Display very difficult to read, interpret/follow Credibility of some elements in question
8
Intolerable
Info confusing/extremely difficult to comprehend
Display unreadable/confusing and/or misleading
9
Improvement mandatory
Impossible
Information and display do not support task (task cannot and should not be executed)
10
Complete redesign required
PILOT DECISIONS
CRITERIA/RATING
ACTION

Appendix C

TOPMS Debriefing Questions

The following questions were used as a (minimum) guide set to solicit comments on the TOPMS. The investigators asked the questions orally and the evaluation pilots' answers and comments were recorded on cassette tape. Each pilot was debriefed individually and not in the presence of the other pilot. Also, the pilots were not shown this list of questions in advance (whereas they were provided the questionnaire (appendix B) as part of the prebriefing package). Question 9 allowed the pilots to offer many unsolicited comments and to elaborate on why they rated the system (appendix B) the way they did.

1. How would a TOPMS fit into your takeoff scan/control philosophy?
   a. How much of the takeoff pilot's attention should it require?
      - When the situation-advisory and engine flags were green?
      - When the flags turned amber or red?
   b. In general, would you relegate the TOPMS monitoring task to the pilot-not-flying? As the takeoff pilot, would you rely on the other pilot for monitoring ...
      - Near rotation?
      - If an amber or red flag came on?
   c. How would a TOPMS display augment or distract you from other sources of information (e.g.,other instruments or view out the window)?
   d. Where do you think the display should be located? How about the location used in this study?
   e. Do you consider the TOPMS suitable for a head-up display?

2. How useful was the analog feature of the CAS/V1 lines? (i.e., the closure of the CAS-line on the V1-line as the airplane neared V1)

3. Where would or did you monitor airspeed - on the TOPMS or the regular round dial?

4. Was retention of the open triangle (marking the initial prediction of where VR will occur) helpful? distracting? or generally ignored?

5. Did you consider the logic and colors associated with the Situation Advisory Flag to be appropriate?

6. Was it acceptable/helpful to switch from the Takeoff Display to the Abort Display once an abort was initiated?

7. What are your comments concerning the stop-point symbols? (Stop-star for maximum wheel/spoiler braking and the Football for showing the stop point for the level of braking being used)

8. What would you change about the TOPMS before it is installed and used on an airplane?

9. Other comments? ......

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16. Abstract

A Takeoff Performance Monitoring System (TOPMS) has been developed to provide the pilot with graphic and numeric information pertinent to his decision to continue or abort a takeoff. The TOPMS information display consists primarily of a runway graphic overlaid with symbolic status, situation, and advisory information including: (1) current position and airspeed, (2) predicted locations for reaching decision speed (V_1) and rotation speed (V_R), (3) ground-roll limit for reaching V_R, (4) predicted stop point for an aborted takeoff from current conditions, (5) engine status flags, and (6) an overall situation advisory flag that recommends continuation or rejection of the takeoff. In this study, 32 experienced multiengine-rated pilots evaluated the TOPMS on the Langley Transport Systems Research Vehicle (TSRV) Real-Time Simulator. They rated the system "satisfactory—good" and judged it to be suitable for implementation on an aircraft. This report describes the TOPMS, the TOPMS simulation, and the results of the simulator evaluation. Appendixes contain the pilot's prebriefing package (written explanation of the TOPMS sent to the pilots prior to their visit), evaluation instructions, debriefing questions, and rating criteria (organized into a flow diagram similar to the Cooper-Harper diagram for evaluation of aircraft handling qualities).

17. Key Words (Suggested by Authors(s)):
Takeoff
Takeoff performance monitor
Head-up/head-down display
Electronic displays
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Simulator evaluation

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