Evaluation of a Takeoff Performance Monitoring System Display

David B. Middleton
NASA Langley Research Center, Hampton, Virginia
and
Raghavachari Srivatsan
University of Kansas Center for Research, Inc., Lawrence, Kansas

A takeoff performance monitoring system (TOPMS) has been developed to provide a pilot with graphic/numeric information pertinent to his decision to continue or abort a takeoff. The TOPMS instrument display consists primarily of a runway graphic overlaid with symbolic status 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-failure flags, and 6) an overall situation advisory flag that recommends continuation or rejection of the takeoff. In this study, over 30 experienced multiengine pilots evaluated the TOPMS display on the Langley B-737 real-time research simulator. The display was well received and judged easy to monitor and comprehend.

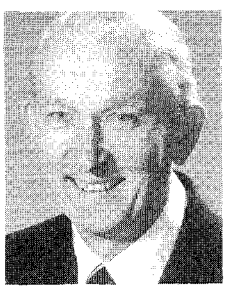
Introduction

PRESENT-DAY flight management systems generally do not provide any aids for the takeoff flight phase. Yet, statistics compiled over the years indicate that accidents in the takeoff phase account for about 12% of all aircraft-related accidents. In recent years the accident rate in the takeoff phase has remained constant, whereas it has decreased in all other flight phases.[1] Further, most takeoff-related accidents are attributable to some form of performance degradation, and a large percentage of them could have been avoided had there been a simple, yet comprehensive way to monitor the progress of the takeoff roll.

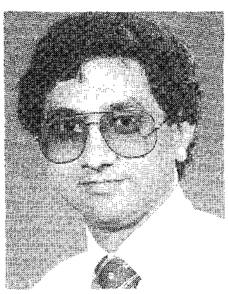
Several single-point speed checks have been proposed,[2] as well as some that deal with elapsed time to reach a point on the runway.[1] Also, a multiparameter aircraft performance margin indicator[3] has been conceived at the Boeing Company. This indicator continuously determines the ability of the airplane to achieve takeoff speed (i.e., V_R) and to brake to a stop within pertinent runway constraints. It does not, however, directly indicate where on the runway the airplane will reach V_R or where the stop point will be, but it does show the pilot how near he is to losing either his takeoff or his abort option (based on using maximum thrust for the takeoff).

A takeoff performance monitoring system (TOPMS) has been formulated and verified[4,5] in batch simulation at the NASA Langley Research Center, under a cooperative agreement with the University of Kansas Center for Research, Inc. This system incorporates the following features:

1) It calculates a minimum runway length recommended (viz, a balanced field length or BFL) for the particular airplane and existing conditions.



Born in Herndon, Virginia, David Middleton received a B.S. in mathematics from The College of William and Mary in 1959. He continued with graduate studies at William and Mary, the University of Virginia, and the University of Maryland. Employed at the David Taylor Model Basin in Carderock, Maryland, from 1959–62, he performed stability and control analyses (and simulations) of Polaris submarines. Employed at NASA Langley since 1962, Mr. Middleton has investigated simplified guidance and control of both spacecraft and aircraft. He has flight tested an oculometer (eye tracker) and is currently flight testing the subject takeoff performance monitoring system (TOPMS). He is the author of over two dozen technical reports, papers, journal and magazine articles. Mr. Middleton and Dr. Srivatsan jointly received the IR 100 award in 1987 for the TOPMS and also have patents pending on the TOPMS.



Raghavachari Srivatsan received a bachelor of technology degree in aeronautical engineering from the Indian Institute of Technology, Madras, India, in 1977. He received an M.S. degree in aerospace engineering from West Virginia University in 1980, and a doctor of engineering degree from the University of Kansas in 1985. As part of his doctoral research he developed the algorithm for the takeoff performance monitoring system. He also led a design team that developed unconventional airplane configurations at the University of Kansas. Dr. Srivatsan is currently working as an Aerospace Research Engineer with Vigyan Research Associates in Hampton, Virginia.

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2) It determines the runway distance consumed and the remaining distance required to achieve both decision speed V_1 and rotation speed V_R. It also determines the limiting position for reaching V_R (referred to herein as the "ground-roll limit line") as a part of the BFL calculation.

3) It calculates the runway distance required for stopping the airplane from its current position and speed on the existing type of surface by using maximum wheel braking and fully deployed spoilers, but no reverse thrust, and by using the current (measured) level of deceleration (i.e., caused by braking, reverse thrust, runway contaminants, etc.).

4) It monitors engine pressure ratio (EPR) and relates that value to the handbook value appropriate for the given situation; deviations beyond specified limits activate engine-failure flags.

5) It samples all pertinent parameters and summarizes its findings into a single GO or ABORT advisory signal (and flag).

An additional feature of the TOPMS is that it is self-contained and based in the airplane; it is, therefore, airport independent.

This paper describes the development of a display to convey this information to the pilot, and documents a pilot-in-the-loop evaluation of the display using the NASA Langley Transport Systems Research Vehicle (TSRV) fixed-base simulator. The TSRV is a twin-jet airplane in the Boeing 737-100 class.[6] The aim of the study was to design a simple, realistic, and easily interpreted TOPMS display and to investigate pilot acceptance of it in terms of appropriateness, usability, and credibility. Hence, the study did not address such issues as software validation, fault tolerance, and the effects of input errors/noise. However, rather extensive error and failure-mode analyses were conducted when the algorithm was being developed.[4,5] The results of that effort indicated that the TOPMS distance predictions were generally within 5% of the actual distances computed during simulated takeoffs and aborts. The algorithm was shown to be quite sensitive to wind errors and moderately sensitive to temperature and weight input errors. It was given the capability to adjust for friction estimate, accelerometer bias, and scale-factor errors. Further development and testing were recommended.

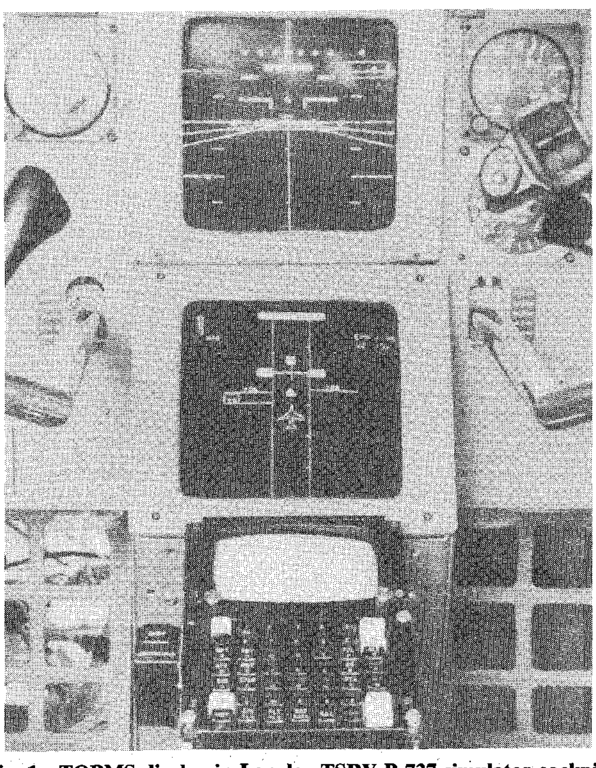

Fig. 1 TOPMS display in Langley TSRV B-737 simulator cockpit.

Description of the Takeoff Performance Monitoring System

Algorithm

The amount of additional runway needed to achieve rotational speed at any instant is a function of the airplane's speed and acceleration. A simple expression for acceleration can be written as

$$a = [THR - D - \mu(W - L)]/m \tag{1}$$

There are uncertainties associated with the onboard determination of thrust in Eq. (1). The friction coefficient μ is a function of tire and runway conditions and is, thus, not easy to obtain. Also, the lift and drag are functions of the square of airspeed. Yet, even with all of these uncertainties, the acceleration provides a good measure of the composite performance of the airplane. The TOPMS algorithm[4,5] attempts to overcome some of these difficulties. It is made up of two parts: a pretakeoff and a real-time segment.

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.[5] In order to do this, the algorithm requires the inputs specified in Table 1. This operation is accomplished prior to the start of the takeoff roll.

The pretakeoff segment computes 1) s_0, the runway distance required to reach V_1 (decision speed), 2) s_3, the runway required to bring the airplane to a complete stop from V_1, 3) s_1, the runway required to reach V_R (rotational speed) from V_1 with one engine failed, and 4) s_2, the runway required to attain a specified height above the runway (35 ft used in this study) from the V_R point after experiencing an engine failure at V_1. The initial ground-roll distance 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. The aforementioned distances are somewhat conservative in that no reverse thrust is assumed for stopping, and approximately 1.5 s is allowed for recognizing the advisory flag and initiating the abort. Also, if the takeoff is continued, the throttles are assumed to remain in the same position as when the abort was decided [i.e., the takeoff is made with "scheduled thrust" rather than maximum thrust on the remaining engine(s)].

The real-time segment uses the set of one-time inputs indicated in Table 2 and the measured inputs shown in Table 3 to perform the following functions. Based on the input runway rolling friction coefficient, it generates a set of nominal performance values (see Ref. 5) for the particular takeoff. Then, using this information, the airplane's present position on the

Table 1 Inputs for the pretakeoff segment

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

Table 2 Pilot inputs to the real-time segment

Runway rolling friction coefficient
Runway direction
Runway length
Runway offset

Table 3 Measured inputs to the real-time segment

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

Table 4 Flag colors and meanings

Situation advisory flag	
Color	Recommendation
Green	Continue takeoff
Flashing amber	Can continue or abort takeoff
Red	Abort takeoff
Engine flag	
Color	Meaning
Green	Engine normal
Red	Engine failed

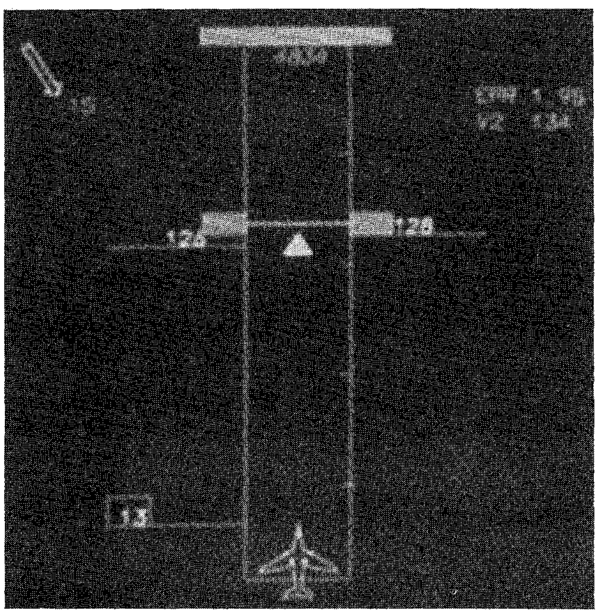

Fig. 2 Typical TOPMS display for a balanced field.

runway, the runway needed to achieve rotation speed, and the runway needed to bring the airplane to a complete stop are computed. After allowing the engine dynamics caused by throttle movement to settle down, the runway rolling friction coefficient and the nominal performance values are recomputed during the takeoff roll. The real-time segment also monitors the health of the engine.

Display Format and Symbology

Figure 1 shows the location of the TOPMS display in the TSRV cockpit (screen in center of photo). This screen is normally the horizontal situation indicator (HSI), but before and during the takeoff, the TOPMS display appears here. Then, immediately following main-wheel liftoff, the TOPMS display is replaced by the regular HSI navigation information.

At the completion of the pretakeoff segment, the display comes up in a default mode, as shown in Fig. 2. In this mode the runway length is scaled to the calculated BFL (shown in the figure as 4834 ft). On the right edge of this graphic are

Table 5 Conditions and colors for the situation advisory flag (SAF)

SAF color	Flight condition
No visible flag	1) Takeoff is proceeding normally.
Green	2) No engines have failed; airplane can reach V_R before reaching the ground-roll limit, but *cannot* stop within the distance remaining. 3) One engine has failed at a speed greater than V_1; however, the airplane can reach V_R before reaching the ground-roll limit line, but *cannot* stop within the runway distance remaining.
Flashing amber	4) One engine has failed at a speed greater than V_1; however, the airplane can reach V_R before reaching the ground-roll limit line and *can* stop within the runway distance remaining.
Red	5) Predicted rotation point is beyond ground-roll limit line. 6) Both engines have failed. 7) One engine has failed and speed is less than V_1. 8) Longitudinal acceleration is not within the specified error band (e.g., 15%) of the nominal value predicted by the algorithm for the throttle setting being used.

1000-ft tick marks, starting at the departure end (top). Also, at the top of the runway graphic is a rectangular colored box, which operates as a GO/ABORT situation advisory flag. The color of this flag indicates the instantaneous advice given by the TOPMS for continuing or aborting the takeoff, as indicated in Tables 4 and 5.

At the lower end of the runway graphic is an airplane symbol whose nose marks current longitudinal position. (By choice, the airplane symbol did not move laterally during this study.) To the left of the runway symbol (opposite the nose of the airplane) is a horizontal line with a box at one end. The line further represents the airplane's longitudinal position, and the number inside the box is calibrated airspeed (CAS) in knots. (The line and the box advance down the runway along with the airplane symbol.) Note in Fig. 2 that the nose of the airplane is about 500 ft from the starting end of the runway; this increment is called the "runway offset" and represents where the on-ramp being used intersects the runway. The takeoff roll begins here.

Further up the runway a shaded triangle is shown; its apex indicates the longitudinal position where V_R will be achieved based on current conditions. The line to the right of the runway further represents this position, and the number (128) on the line gives V_R in knots. Similarly, the line and number to the left indicate V_1 and where it will occur.

In reality, there are two triangles in Fig. 2 – one lying on top of the other. The shaded triangle represents the instantaneous predicted point for achieving rotation speed V_R, and the open triangle (hidden) marks the pretakeoff prediction of this point. The open triangle is thus stationary, but the solid triangle and the V_1 and V_R lines move to indicate the updated positions.

Just above the position of the triangles is a line that stretches across the runway, with a colored box attached at either end (the boxes lie outside the runway). This line represents the ground-roll limit for reaching V_R. The boxes represent engine health flags (see Table 4).

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. The tick marks on the right

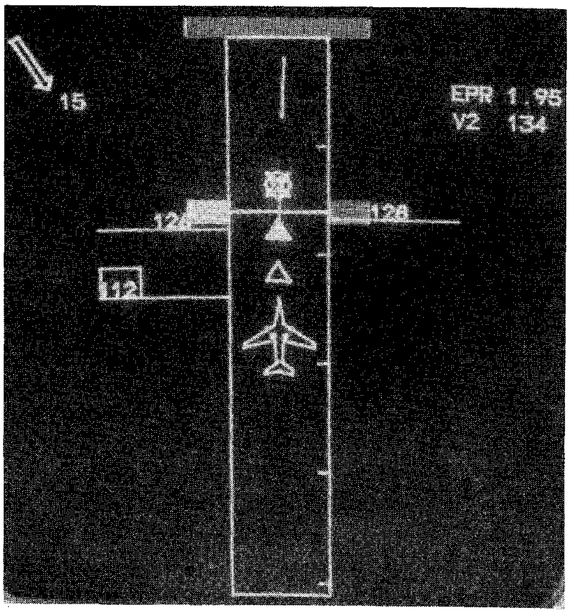

Fig. 3 TOPMS display at 112 knots, showing right engine failed.

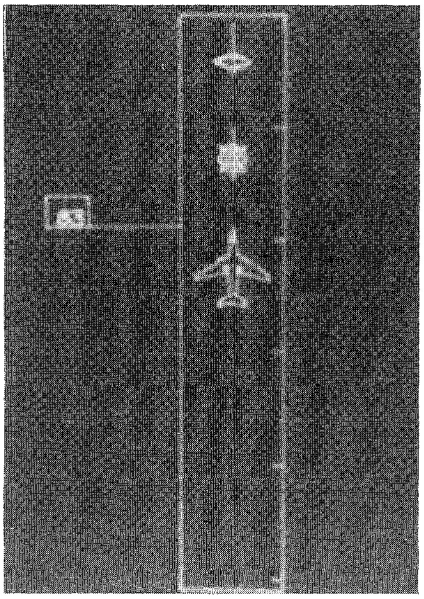

Fig. 4 TOPMS abort display.

edge of the runway represent 1000-ft marks starting from the takeoff end of the runway (top of the picture). The recommended takeoff EPR setting and the second segment climb speed V_2 in knots are shown at the top right corner of the display for reference. And finally, the number under the situation advisory flag (SAF) at the end of the runway gives runway length in feet. On completion of the pretakeoff computation, this number shows the BFL (in feet); it then changes to actual runway length when the pilot enters the appropriate value.

Figure 3 shows a situation with the airplane well into the takeoff run. As is seen in the CAS box to the left of the airplane symbol, the airspeed is 112 knots. The apex of the unshaded triangle (stationary) represents the point at which V_R should have been achieved based on pretakeoff computations. The solid triangle and the V_1 and V_R lines have shifted upward, representing the current predictions of where decision speed and rotation speed will occur. The right engine flag is red, indicating a right engine failure. The engine problem has

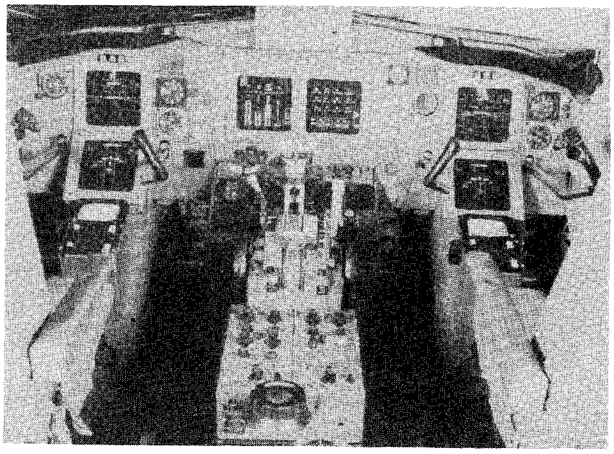

Fig. 5 Cockpit of the Langley TSRV B-737 simulator.

caused the triangles to separate noticeably. The summary SAF (at the top end of the runway) is also red, indicating that the TOPMS recommends aborting the takeoff run. A star symbol with a circle around it is seen just above 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 wheel braking and fully deployed spoilers, but no reverse thrust. To keep the dynamic display relatively uncluttered, the star is kept masked until the stop point is beyond the ground-roll limit line; but, when it crosses this line and becomes visible, the runway-length numeric is removed. Also, when the star reaches the end of the runway, it jumps beyond the SAF and blinks.

The initiation of an abort (executed by the rapid pullback of the throttles) causes most of the takeoff information to be removed, leaving only information pertinent to the abort. Figure 4 shows an abort display. The solid and open triangles, the V_1 and V_R lines, the ground-roll limit line, the V_2 and EPR numerics, and the engine flags are removed from the display. The calibrated airspeed in the box to the left of the airplane symbol is replaced by ground speed in knots. The star-in-the-circle symbol remains (representing the stop point using maximum braking, full spoilers, but no reverse thrust). A new symbol (a football) appears on the display indicating the position where the airplane will stop using the current level of deceleration (in this case, less than full braking).

Description of Simulation

Transport System Research Vehicle Model

The simulation is accomplished with a 6-deg-of-freedom nonlinear model of the Langley TSRV B737-100 airplane, consisting of a detailed aerodynamic package, an engine model, and a landing gear model. The aerodynamic package incorporates two- and three-dimensional table lookups for aerodynamic coefficients and adjusts them for ground effects. The engine model includes detailed ram-air and temperature effects. The simulation package also contains modules that provide realistic sensor noise effects.

TSRV Simulator Cockpit

Pilot interface to this simulation model is accomplished through a fixed-base replica of the aft flight deck of the TSRV (Fig. 5). This aft flight deck incorporates all 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. In addition, they share a pair of engine displays (CRT's on the center panel between them). The aft flight deck of the TSRV does not have an out-the-window view; consequently, the simulator cockpit did not have one.

The upper CRT (directly forward and just below the glare shield) is a modified electronic attitude display (EADI). In addition to its normal features, the EADI had a superimposed runway (while the airplane was on or near the ground) consisting of a centerline and two lines on either side dividing the runway width into four equal strips. For this study the SAF from the TOPMS display was repeated on the EADI.

The CRT below the EADI normally serves as an HSI. It displays the maps and other data used for navigation. In this study it also displayed the TOPMS information when the airplane was on the ground. Once main wheel liftoff occurred, the TOPMS display disappeared and was replaced by the normal HSI information.

Below the HSI is the NCDU. It consists of a small black and white CRT display and an alphanumeric keypad (see Fig. 1). The pilot uses this unit to enter navigational and other information into the flight control computer; it also serves as the pilot's 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 Tables 1 and 2, and then activates the pretakeoff computations. Once these computations are complete, the HSI screen shows a default TOPMS display similar to Fig. 2. The pilot then enters the actual runway length, and the display is updated accordingly. The system is now ready for takeoff.

During the actual takeoff roll, the pilot flying moves the throttle to an intermediate setting, waits for the EPR to reach an intermediate value, and then moves the throttles to near the recommended takeoff setting; the other pilot makes the final adjustments. The EADI image of the runway is the primary visual cue used by the pilot to maintain the airplane on or near the runway centerline. When rotational speed is reached, the pilot pulls on the modified column (see Fig. 5) until the airplane's pitch attitude reaches about 20 deg; he then returns the columns to neutral. As the wheels lift off the runway, the TOPMS display is automatically replaced by the standard HSI displays (however, the runway graphic on the EADI remains until it goes out of sight). The simulation ended soon after takeoff.

Evaluation

The TOPMS is being evaluated in several phases. The algorithm has been analyzed and verified in batch simulation[5] for accuracy and sensitivity to various input parameters. In the current study the display was viewed, tested, and rated by over 30 experienced (see Table 6) multiengine pilots on the Langley TSRV B-737 real-time simulator. Based on their comments and suggestions, the display and driver-logic are being revised and will be re-evaluated on this same simulator. Subsequently, a selected or "final" configuration will be programmed on the flight management computer of the TSRV B-737 airplane and flight tested.

The real-time simulation sessions each involved two pilots working as a crew. Most had not met before. The subject pairs received a short writeup and a 10-min video briefing on the system before proceeding to execute a program of takeoffs/aborts and monitoring the TOPMS display for approximately 2 h (1 h as the pilot flying and 1 h as the pilot not flying). During several practice runs at the beginning of the session, the crews agreed on their division of duties/operating procedures (e.g., what speeds or events the pilot not flying would call out to the pilot flying). The session itself consisted of approximately 20 runs for each pilot, covering a variety of conditions. In particular, the conditions included normal takeoffs, reduced-thrust takeoffs (both intentional and as an error condition) ambient temperatures from 0 to 100° F, pressure altitudes from sea level to 5000 ft, a variety of wind conditions (both known and as an error condition), numerous runway lengths, light to heavy gross weights, unannounced deployment of spoilers to create excess drag, dry and slushy runway surface conditions, and several combinations of the above. The runs were selected to exercise, as a minimum, all of the SAF conditions shown in Table 5.

At the conclusion of the simulation session, each pilot was asked to evaluate the system independently by 1) making free comments, 2) answering specific questions, and 3) giving a "goodness" rating for the TOPMS display. The rating (on a scale of 1-10) was extracted from a diagram (Fig. 6) similar to the one associated with the Cooper-Harper scale[7] for aircraft handling qualities. The numerical ratings are averaged in some cases, but are not otherwise treated statistically because of their subjective nature.

The pilots were instructed (in writing and verbally) not to let factors such as unfamiliar controls and displays or the location of the TOPMS in the simulator cockpit influence their rating of the TOPMS display per se. (The pilots were, however, encouraged to identify desirable/undesirable features of the overall simulation.)

Table 6 TOPMS evaluation pilots

Pilot categories	No. of pilots	Flying hours, avg.
Air Force	7	3600
NASA/FAA	8	5800
Airlines (Delta, Eastern, Northwest, Pan Am, Piedmont, TWA, United)	9	16500
Industry (Boeing, Lockheed, McDonnell Douglas)	4	6000
Other	4	5200
Total	32	7000 (avg.)

Results

As previously indicated, 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 (Fig. 6) was based on criteria related to the appropriateness for the task and how easy/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 this type of information in the 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. On the one hand, it might add to his currently defined procedures and scan pattern, but on the other hand, it might eliminate some tasks or reduce the number of times certain elements had to be performed. In any event, the pilots felt that it would provide the crew with valuable additional information that is currently not available in the cockpit.

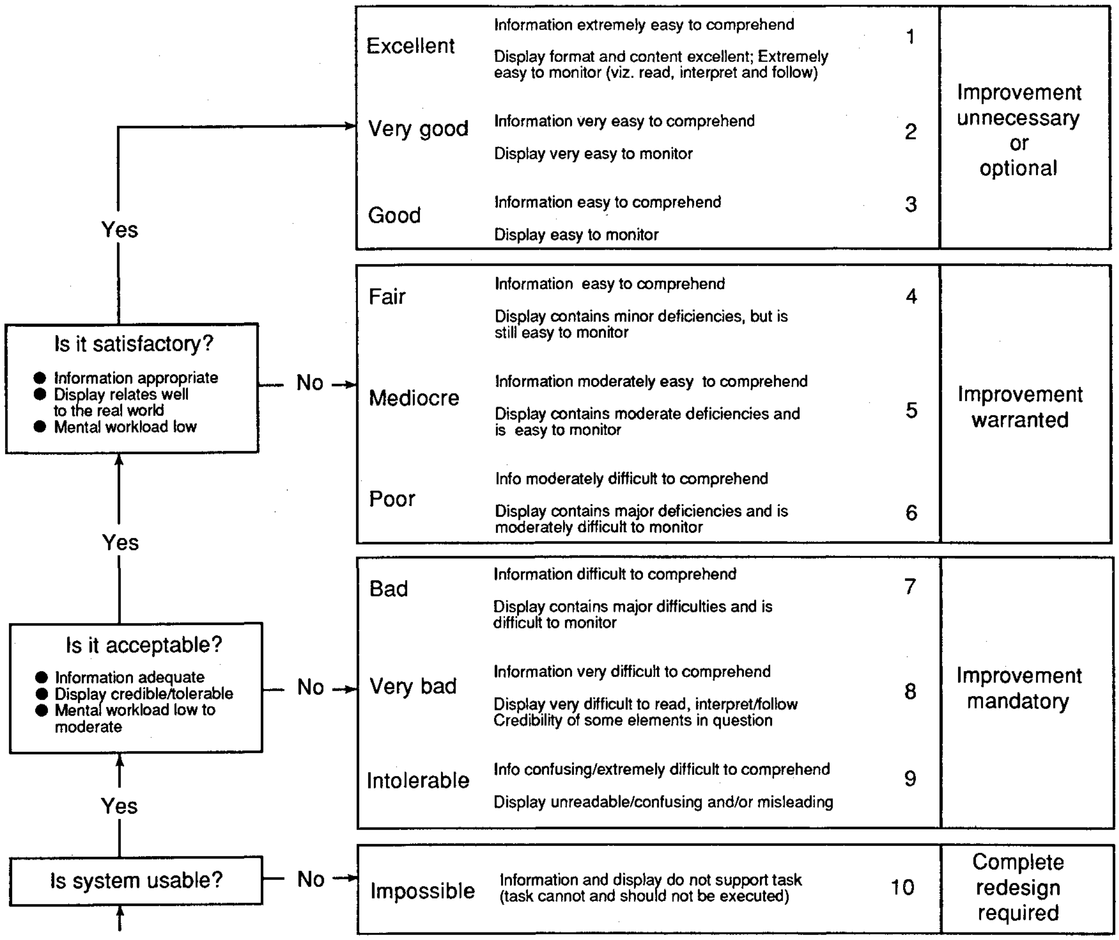

Fig. 6 Evaluation chart for the TOPMS simulation study.

The more significant comments offered by the evaluation pilots are summarized as follows:

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 would also like to have the same display available and, in addition, he would like to have a simplified version projected onto or in the vicinity of his windshield as a head-up display.

2) The pilots indicated a strong preference for the following information:

a) Visual indication of the limit of allowable ground roll for reaching V_R (viz, the ground-roll-limit line).

b) Pictorial and numeric indication of the BFL.

c) 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).

d) Improved analog indication of the difference between airplane's current airspeed 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 by their perceived closure rate. (This same information is available on most dial-type airspeed instruments, but is not nearly as easy to monitor.)

e) Expected locations (symbols) where the airplane can be braked to a stop from its current location and velocity.

f) Graphic indication of the airplane's current position and velocity with respect to the 1000-ft markers on the side of the runway, as well as to the above references.

g) SAF, which summarizes all of the takeoff-related information into a single source.

h) Right and left engine-failure flags.

Items a–h are not prioritized. The symbology and colors used to impart this information were considered 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 scan angle from the windshield to the HSI location was considered undesirable, but acceptable.

4) Some pilots suggested that the TOPMS airplane symbol be driven in the lateral plane; others 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 heads-up display and to be more conservative in the logic governing the amber-flashing mode of the SAF (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 and/or alphanumeric message windows. All of these comments are being considered in a revision of the TOPMS, which will be checked out in the simulator and then flight tested.

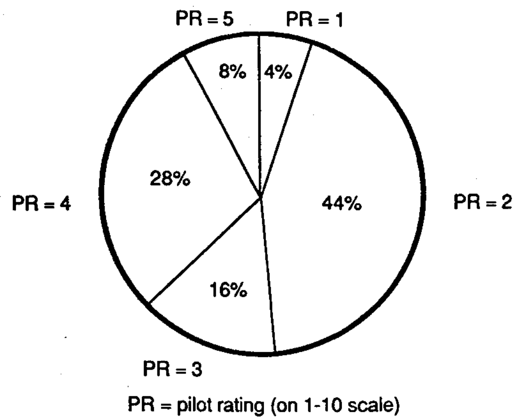

Fig. 7 Distribution of pilot ratings of the TOPMS.

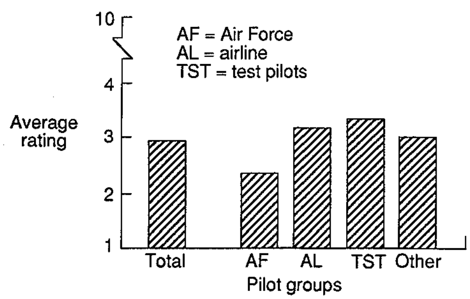

Fig. 8 TOPMS ratings by pilot experience group.

Pilot Ratings of Display

Twenty-five experienced multiengine-rated pilots rated the TOPMS using the flow diagram/scale shown in Fig. 6. The ratings obtained ranged from 1-5 according to the distribution shown in Fig. 7. The pilots were grouped according to their current jobs 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 Fig. 8. The average rating given by the 25 pilots was approximately 3, corresponding 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); however, the Air Force pilots probably had more takeoffs per hundred hours of flying time because of the nature of their missions. The TOPMS rating was a convenient way of quantifying the pilot's opinion of the value or merits of the display, but it could 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 "very good," or 2, because they considered the information obtained from the display quite valuable from a safety 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., cockpit layout) than to the TOPMS algorithm/display.

Concluding Remarks

The display evaluated in this study provides the first indication of how pilots might accept and use the predictive and status information generated by the TOPMS algorithm. The display was well received by over 30 experienced pilots, and all encouraged its continued development. They rated it "satisfactory" (or 3 on a scale of 1–10). In particular, they felt that in its tested form/location, it would require deliberate but low-effort monitoring. They recommended that the pilot not flying should have primary responsibility for monitoring it and announcing events or advisories to the pilot flying. A large number of the pilots speculated that if the TOPMS were implemented as a head-up display, the pilot flying would be able to glean a lot of information from it without being distracted from his primary task of steering the airplane while looking down the runway. Also, the abort display would be quite useful to him in stopping the airplane at a selected location (e.g., near a turnoff). The follow-on simulator evaluation has incorporated the head-up TOPMS display and some head-down display refinements suggested by the pilots. Future plans include flight testing a selected configuration.

It is recognized that substantial engineering problems related to implementation of a "working" TOPMS still exist. They include software validation and provision of improved performance data to the algorithm. In particular, determination of proper runway friction coefficients for wet and contaminated surfaces remains elusive. In the meantime, this study has provided a step forward by presenting a desirable takeoff/abort advisory display, which will become even more desirable as the related performance engineering problems are solved.

References

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