PILOT EVALUATION OF A TAKE-OFF MONITOR DISPLAY

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Abstract

A take-off performance monitor is an instrument designed to provide performance information during take-off to support the crew in their decision to continue or abort the manoeuvre in line with operating procedures. The design of the display of a take-off monitor is crucial to the successful adoption of the instrument on the flight deck of an aircraft. This paper presents the findings of an evaluation carried out on a take-off performance monitor display, which suggest that the display should be accepted by the pilot community and therefore also on the flight deck.

1 Introduction

Take-off is the phase of flight during which the aircraft accelerates down the runway and achieves an airspeed that allows it to become airborne and climb away over any obstacles. It is defined by the International Civil Aviation Organization (ICAO) as starting with the application of take-off power and ending in the continued case, when the aircraft attains an altitude of 35 feet above the runway elevation [1]. Completing the manoeuvre within the runway constraints is a performance issue and, in large transport aircraft operations, aircraft need to have sufficient thrust to provide the necessary acceleration to achieve the rotation speed V_R and climb safety speed V_2 for the particular operating conditions (weight, altitude, temperature, wind speed, etc.) within the take-off distance available (TODA).

TODA is defined by the Federal Aviation Administration (FAA) as 'the TORA plus the length of any remaining runway and/or clearway beyond the far end of TORA'. TORA is the 'take-off run available', defined as 'the length of runway declared available and suitable for the ground run of an airplane taking off'. 'Clearway' is a 'rectangular area beyond the end of a runway cleared or suitable for use in lieu of runway to satisfy takeoff distance requirements' [2]. All runways supporting large transport operations are required to declare the TODA and TORA.

1.1 Protection through scheduled performance

Large transport aircraft operations are regulated by Part 25 of the regulations, which requires aircraft to have adequate performance to allow them to be brought safely to land in the event of an engine failure during any phase of flight. This includes take-off and, due to performance constraints, the take-off is accordingly split into two parts, with the Decision Speed V_1 separating the two.

In the first part, before V_1, the aircraft will still be in the early stages of the take-off run and consequently, if an engine failure is experienced, it is safer to abort the run than to continue it. Another constraint is the limited rudder authority at low speeds, which would preclude the authority to counter the yaw caused by the asymmetric thrust due to the engine failure. In such cases, it would not be possible to maintain the aircraft on the runway and consequently the run has to be aborted.

In the second part of the run, past V_1, the aircraft will be approaching the speed that will allow it to become airborne and it is safer to continue the run and become airborne on the remaining engines than performing a high energy abort and attempting to bring the aircraft to a halt in the remaining runway. Consequently, a take-off run is not aborted after V_1 if an engine failure is experienced unless the aircraft is clearly not airworthy.

Prior to dispatch, the aircraft operator is required to ensure that the TODA and TORA of the runway are equal to or exceed the calculated (scheduled) distances required (termed TODR and TORR respectively) for the aircraft in the expected operational environment. The operator is also required to ensure that the accelerate-stop distance available (ASDA) is also adequate in the event of needing to reject the run at the decision speed V_1. Alternatively, the operator can determine the maximum regulated take-off weight (RTOW) that will allow the take-off to be performed safely within the runway lengths or, if the runway is not limiting, may schedule a reduced thrust setting for the expected dispatch weight to still satisfy the runway requirements. This latter procedure is a commonly adopted practice within airlines as it prolongs engine life and time-on-wing.

There are a number of considerations built in the scheduled calculations to allow for normal variations in operating parameters such as actual aircraft weight and wind at the time of departure.

1.2 Protection in real time

Once the aircraft is dispatched, the crew set the scheduled thrust and, from a performance perspective, let the aircraft accelerate to achieve the desired airspeed. During the run, a pilot depends on his human perception and secondary indications such as the speed trend vector and engine instruments to confirm that the aircraft is indeed accelerating adequately. These sources are either not reliable or are not direct indications of whether the aircraft will complete the take-off run within the runway constraints. As a result, the crew are effectively constrained to assume the aircraft will achieve the desired level of performance and become airborne within the allowances catered for in scheduled performance.

The several leeways allowed for prior to dispatch normally prove adequate to allow the aircraft to become airborne within the runway constraints or come to a halt in the event the run is rejected. Indeed, the track record of take-off manoeuvre confirms this. However, there have been a number of occasions where the runway lengths did not prove adequate or the procedure failed to provide adequate protection to ensure a safe continuation of the manoeuvre. This is testified by the several accidents that have occurred over the years. Two of the more recent high profile accidents are the fatal MK Airlines B747 overrun at Halifax in 2004 and the Singapore Airlines tail-strike at Auckland in 2003. In the latter accident, the aircraft became airborne very close to the stall speed and the stick shaker subsequently activated, but fortuitously for the 389 passengers and crew the aircraft managed to slowly recover. In this case, it was only circumstance that the passengers did not share the same fate as those on the fatal Air Florida B737 flight from Washington State in 1982. On that occasion, the aircraft stalled and crashed into the Potomac river, killing 74 of the 79 passengers on board and another 4 on the ground.

Although the major causal factors leading to the Singapore and Air Florida accidents were very different (the former was due to an erroneously low weight keyed into the flight management computer (FMC) whilst the latter was caused by icing on the wings and engine pressure probes), both aircraft had inadequate thrust for the operational conditions and therefore exhibited significant underperformance. In both cases, the inadequate acceleration was not positively identified by the crew and the run was not rejected. Underperformance is difficult to detect and even then, it would be very difficult to quantify its effect on distance requirements. This must also be considered in view of the high crew workload during take-off and operational pressures to keep the flight on schedule. Coupled with the fact that most crews will never experience an over-run or even a close encounter in their entire career, it is understandable that in such circumstances, crews could hesitate to abort the run and, in doing so, seal the fate of the flight.

Indeed, the transcript of the cockpit voice recorder of the Air Florida flight indicates that the first officer realized that something was not right [3] but the crew failed to take positive corrective action that could have averted the accident. In the Singapore Airlines incident, the crew did not seem to be aware of the aircraft's underperformance during the ground run [4].

The crew's failure to correctly detect the dangers of the aircraft's underperformance and reluctance to abort the run in such accidents is very significant. Although statistics associated with the occurrence of underperformance during take-off are not available, it is very evident that that there may be many more occurrences where the aircraft will be underperforming but, due to the conditions of the day, the runway would prove adequate. The take-off would be completed successfully and the event gone unreported. Although the aircraft would not have overrun, underperformance is a critical issue as it is questionable whether an aircraft that is significantly overweight or has inadequate thrust should be taken into the air as the second segment climb performance could be significantly compromised. Indeed, the Air Florida B737 did become airborne within the runway constraints at Washington but stalled within a mile of the runway threshold.

1.3 The take-off performance monitor

The dangers of underperformance during take-off have been identified before the introduction of jet transport aircraft in commercial aviation [5] and concerns have been voiced repeatedly since. As a result, the idea of the 'take-off monitor' was conceived over 55 years ago. The instrument would provide indication, in real-time during the take-off, of how the run would be progressing. The technology available, however, which was then based on electro-mechanical instrumentation, precluded the realization of equipment that would be adequately reliable to merit its introduction in the cockpit. Influencing the pilot in the decision to continue or abort the run, the instrument has to be sufficiently reliable to correctly identify instances that warrant the rejection of the run whilst maintaining the probability of incorrectly leading the crew to abort the run to a low level that is acceptable in normal operation. This latter requirement proves to be very stringent, since unnecessary aborts are not only considered a nuisance in operations, but can also contribute to a higher risk of accident.

The accident report of the Air Florida B737 accident catalysed further activity in take-off performance monitor design. The 1980s ushered the widespread use of computer technology in many industries, including commercial aviation. As a result, adequate technologies that could support the design of reliable instruments were becoming available. Several designs and approaches have since been proposed, but none have been introduced in commercial operations to date.

2 The Cranfield Take-off Performance Monitor (TOPM)

Cranfield University has conducted a detailed study of candidate methods for take-off performance monitoring, taking into account the usefulness of the information, its accuracy and reliability. This study concluded that the optimal method of take-off performance monitoring would be to predict, in real-time during the take-off, the distance the aircraft will cover during the ground run, that is, up to rotation. The distances covered in the later phases of the take-off run, namely the rotation and airborne phases, cannot be predicted with sufficient accuracy due to the large variation in piloting techniques between crews. Non-predictive monitoring, which considers only the progress achieved and does not predict aircraft performance further down the runway is considered to not be adequately representative of the eventual outcome of the take-off attempt.

2.1 The Cranfield Display

A second major consideration in the studies carried out was the instrument display. A crucial requirement was that the display provides an optimal level of information in a simple manner that is conducive to the quick, unambiguous assimilation of the information presented. Given the high workload of the crew during take-off, the instrument should not distract the crew or increase their workload.

The solution proposed for the display was the presentation of the runway distance leeway predicted to be available at the time of rotation. This leeway is presented in terms of a percentage for two major reasons. Firstly, this allows the crews to identify the percentile in which the aircraft is actually operating and secondly, the authors are of the opinion that the human being is more capable of assimilating situations using ratios and percentages than using absolute values in these circumstances. The use of percentages also ties in with the concept of net and gross performance. As take-off performance is expected to have a standard deviation of 3% and net performance introduces a 15% leeway to cover 5 standard deviations (all but 1 in 10^7 of cases), a graphical measure of the *actual* percentage leeway available during the run can provide the crew with an indication of how the take-off is progressing. Indeed, it is the percentage leeway of performance and not the absolute leeway that is a direct measure of the probability of success of the manoeuvre. For example, the performance may be better than average, less than average but well within limits, borderline or inadequate. The authors consider the provision of such information more appropriate than, for example, absolute distances. This is because the probability of success of the manoeuvre (and thus also the risk of collision) is linked directly to the percentage leeway and not absolute leeway. Indeed, a 300m leeway provides a smaller margin for a heavily laden aircraft than a lighter counterpart.

As a result, the Cranfield display presents the percentage leeway in the form of a bar extending from the reference line of the airspeed indicator (ASI). The length of the bar is a linear function of the performance leeway with respect to scheduled performance. The display is located adjacent to the ASI as the ASI is the most critical instrument during take-off and is currently also used to measure of performance. The extension from the reference line of the ASI was a natural choice, as this concept is standard in primary flight display presentation. A number of graduations next to the displayed bar provide a standard scale to support the correct assimilation of the quantitative information. The Cranfield display is presented in Figures 1 to 7. One graduation in line with the reference line of the ASI coincides with net performance, which is also the reference threshold of performance. If the aircraft's performance is adequate and therefore a leeway is available, the bar extends upwards from this graduation. It is coloured green, denoting adequate performance. The size of the green bar is a measure of the excess leeway, or the safety margin associated with the manoeuvre.

Three other graduations are linked by a vertical bar, forming a bracket in the shape of an 'E'. The middle graduation denotes gross performance. If the green bar extends to this mark, the aircraft would have average performance and have a 15% leeway from the scheduled threshold. The bracket extends on either side of the gross performance mark and denotes the boundaries of 'normal performance'. These boundaries are nominally set at ±2.5 standard deviations, with the bracket statistically covering just under 99% of all runs. The reasoning behind this choice of limits is presented later in the text.

A red bar extending below the reference graduation (net performance) is displayed when performance is less than the scheduled threshold. The length of the bar is proportional to the amount of excess runway being covered. No graduations are displayed in this area, as the performance is inadequate and there is no scope of quantifying the inadequacy other than by the length of the bar to quantify the gravity of the situation.

2.2 Display operation and interpretation

The display suggests the classification of performance into 4 categories, namely normal, high, marginal and inadequate. In normal performance, the green bar would extend to a level within the bracket. This level of performance indicates a healthy situation with no real concerns regarding the risk of overrun, as the decision speed V_1 will be reached before the scheduled distance down the runway, thus allowing a greater leeway for braking or to become airborne.

If the green bar extends to the centre graduation, then aircraft performance would coincide with average performance. If, in comparison, the bar extends to the upper half of the bracket (Figure 1), the performance would be better than average but still considered normal. A bar extending only to the lower half of the bracket would likewise indicate that performance would be less than average but normal. Such a situation would not be alarming as reasonable leeway would still be available. There are two reasons for selecting 2.5 standard deviations as the limits of extension of the bracket from gross performance. The first is that this is half the leeway to net performance, which is the minimum allowed performance at 5 standard deviations from the average. This results in four graduations being equally spaced apart, which is, from a visual point of view, desirable. The second reason is that if the bar extension falls outside the bracket, the performance can be classified as 'abnormal' since it would happen on only 1% of all runs.

Marginal performance would be indicated by a green bar extending to a level below the bracket (Figure 3). Although the aircraft would be performing better than the scheduled limit and therefore theoretically within the acceptable level of risk of accident, leeways are now low and the aircraft would be performing in the 0.5 percentile bracket. From a regulatory point of view, the aircraft is still performing better than the minimum limit, suggesting that the aircraft will successfully clear obstacles and therefore the run need not be aborted. As a result, the decision to continue or reject the run is considered a matter of airline procedures at this stage. Procedure may, for example, require the rejection of the run only if the performance indication is 'subnormal' below 80kts, where the risk and implications associated with rejection would be less than those associated with continuing the run.

High performance, where runway leeway is in abundance, is indicated by the green bar extending beyond the bracket (Figure 2). The length of the green bar correctly suggests a low risk associated with the manoeuvre and good performance 'health'. Such circumstances, however, unless deliberately conditioned with, for example excess thrust application, would be expected on only 0.5% of all runs and this suggest that the cause of such performance should be investigated after take-off. Indeed, such circumstances may be the result of situations of incorrect fuel loading, which may jeopardise the continued safety of the flight.

Inadequate performance is displayed by a red bar extended down from the reference line (Figures 4 and 5). The implications of such performance are that the continued run is not viable and that rejection of the run from V_1 is likewise not viable. Viability, in this context, refers to whether the run will exceed the scheduled distances which, in the limiting case, will result in the collision with obstacles at the end of the runway. The implication in such situations is that the run should be aborted as early as possible to reduce the risk of low-speed overrun. The longer the red bar, the earlier the run needs to be aborted if the risk of overrun is to be kept low.

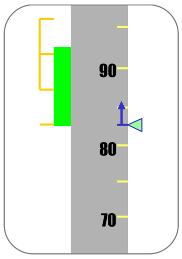

Figure 1: Normal performance.
The performance of the aircraft is slightly above average (gross) performance.

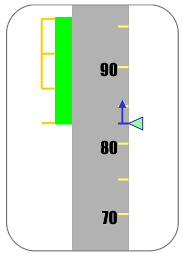

Figure 2: Abnormally high performance.
The performance of the aircraft is well above average (gross) performance.

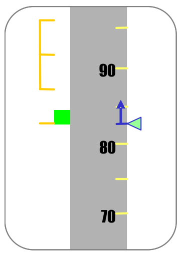

Figure 3: Marginal performance
The performance of the aircraft is well below average but still within scheduled (net) allowances .

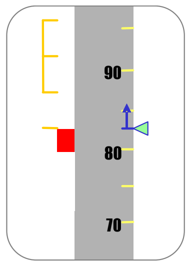

Figure 4: Inadequate performance
The performance of the aircraft is just outside scheduled (net) performance.

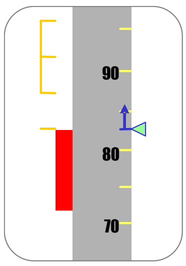

Figure 5: Inadequate performance
The performance of the aircraft is well outside scheduled (net) performance.

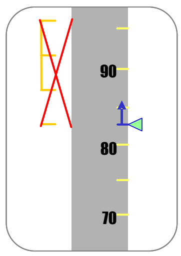

Figure 6: System Failure

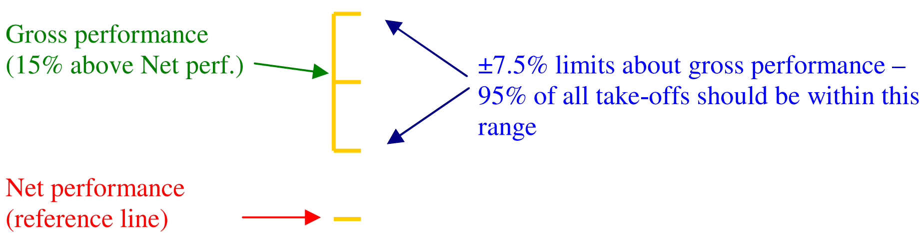

Figure 7: The interpretation of the display graduations.

3 The Evaluation Programme

The evaluation of the take-off performance monitor display was carried out using volunteer pilots in the School of Engineering's flight simulator [6].

3.1 The Cranfield flight Simulator

The School of Engineering's flight simulator, known as the 'Large Flight Simulator' (LFS) at Cranfield, is based on an ex-British Airways Boeing 747-200 training device that has been modified extensively into a research simulator. The software has been replaced completely, a new set of primary visuals installed and the cockpit hardware modified to support research needs. In this respect, all flight and engine instruments were replaced with colour cathode ray tube (CRT) displays to replicate the Boeing 747-400 Primary Flight Display (PFD), Navigational Display (ND) and Engine Indication and Crew Alerting System (EICAS) displays (Figure 8).

Figure 8: The LFS cockpit

An airbus-style Flight Control Unit (FCU) was installed as well as two airbus-style sidesticks to augment the existent control columns.

The simulation software has been developed in-house and runs on four computers interconnected via a local area network (LAN). The primary visuals are generated by an SGI Onyx II machine running Multigen-Paradigm Vega software driving SEOS projectors to provide a 180° horizontal and 40° vertical field of view. This provides a good immersive environment that supports pilot evaluation of prototype avionics software and concepts. The simulator has an instructor station located where the flight engineer would be on a Boeing 747 classic. From this station, scenarios and the simulation environment can be controlled.

3.2 The participants

A total of twelve volunteer pilots participated in the evaluation. These were a mix of Boeing 737, 757, ex-767 and B747-400, Airbus A320 and A330 and Fokker 100 pilots. Ages ranged from 25 to over 65, two were training captains, one was in management and the rest were line pilots. Flying experience ranged from 3,500 hours to over 10,000 hours. The group therefore consisted of pilots with a mix of experience flying aircraft with different manufacturer philosophies and with a mix between short-haul and long-haul experience.

3.3 The experimental procedure

All pilots were given a pre-session briefing note describing the theory of scheduled performance and how the take-off performance monitor operated. Pilots were also briefed to adhere to a set of typical airline standard operating procedures (SOPs), which included rejecting the take-off if an engine occurred before V_1 and continuing it if a failure is experienced after V_1.

Prior to the start of the simulator session, each participant was given a safety briefing and once inside the simulator, was also briefed on the differences between the aircraft they normally fly and the LFS cockpit environment. All pilots were given the choice of inceptor, selecting between side-stick and column and all volunteers – including Airbus pilots – opted for the control column. All take-off runs were conducted with a single pilot sitting in the left hand seat.

The scenario selected was Runway 29 at Monterey, California. This runway represents a field-limiting case for a Boeing 747 and the aircraft was positioned at the threshold of the runway at the beginning of each run.

11 of the 12 participants took part in the simulator sessions. All were given four practice take-offs, 3 of which included engine failures. These runs were introduced for familiarization purposes only and were not recorded.

Each pilot was then presented with a number of scenarios and allowed one take-off run for each scenario. The scenarios are listed in Table 2.

The 25 scenarios are classified into 9 categories. Category 1, comprising scenarios 1 and 2, group take-offs without the performance monitor. Categories 2 to 7 group runs with normal, high, marginal, inadequate, improving and decreasing performance. Each category consists of three runs, one 'normal' (without engine failure), one with an engine failure at 10kts below V_1 and one with an engine failure after V_1. The high performance category has 4 runs as it also includes a scenario with engine failure 20kts before V_1. The improving and decreasing performance categories were used to evaluate the effect of dynamic conditions.

Category 8 groups 4 other runs with specific scenarios as described in Table 1.

Category 1 runs were always conducted first, but all subsequent runs were conducted in random sequence between the participants so that bias due to the effect of the order is eliminated from the results.

The pilot response during the run – continuing or rejecting the take-off - was documented as 'correct' or 'incorrect' according to what would be expected in normal SOPs.

Following the simulator session, each participant and the twelfth volunteer was presented with a questionnaire to answer. The questionnaire was designed to provide qualitative data and consisted of several sections, namely:

Section 1: Experience and qualifications
Section 2: Pre-flight briefing
Section 3: Use of the TOPM
Section 4: Understanding of the TOPM display
Section 5: Training issues

4 Results

The main results of the questionnaire are presented in Table 1. The results of the simulator sessions are presented in Table 2.

Question	Agree	Disagree
TOPM will enhance safety	100%	0%
TOPM interferes with crew monitoring task	17%	83%
TOPM use does not need training	17%	83%
Drawn to look at TOPM	50%	50%
Drawn because TOPM novel	83%	17%
TOPM urges more frequent ASI scan	50%	50%
TOPM interrupts outside scan	33%	67%
TOPM interrupts flight instrument scan	8%	92%
Compelled to abort with marginal performance	25%	75%
Compelled to abort with inadequate performance	50%	50%
Confused TOPM with trend arrow	0%	100%
TOPM increases workload	42% marginally increases	50% no effect 8% substantial decrease
TOPM shows indication of stopping distance left	17%	83%
Safe to continue with a red bar	8%	92%
Red bar compelling to stop without further confirmation	75%	25%
Safe to go with marginal performance	83%	17%
TOPM should be executive (connected to auto braking)	0%	100%
PNF to call out TOPM indication as SOP	58%	42%
Clear policy required for action on TOPM indication	100%	0%
TOPM part of MMEL	8%	92%
Simulator training required prior to TOPM use	83%	17%

Table 1: Main results of the questionnaire.

Category	Run #	Description of run			No. of take-offs recorded	No. of correct actions	% correct actions
		Performance	Failure (EF = engine failure)	TOPM ON			
1	1	Normal	EF 10kt < V_1	No	11	8	73%
	2	Normal	EF after V_1	No	11	10	91%
2	3	Normal	None	Yes	10	9	90%
	4	Normal	EF 10kt < V_1	Yes	11	11	100%
	5	Normal	EF after V_1	Yes	8	8	100%
3	6	High	None	Yes	9	9	100%
	7	High	EF 20kt < V_1	Yes	11	11	100%
	8	High	EF 10kt < V_1	Yes	7	4	57%
	9	High	EF after V_1	Yes	6	6	100%
4	10	Marginal	None	Yes	9	8	89%
	11	Marginal	EF 10kt < V_1	Yes	11	10	91%
	12	Marginal	EF after V_1	Yes	9	6	67%
5	13	Inadequate	None	Yes	11	10	91%
	14	Inadequate	EF 10kt < V_1	Yes	8	8	100%
	15	Inadequate	EF after V_1	Yes	3	1	33%
6	16	Improving	None	Yes	8	8	100%
	17	Improving	EF 10kt < V_1	Yes	8	7	88%
	18	Improving	EF after V_1	Yes	2	1	50%
7	19	Deteriorating	None	Yes	8	7	88%
	20	Deteriorating	EF 10kt < V_1	Yes	7	5	71%
	21	Deteriorating	EF after V_1	Yes	3	1	33%
8	22	High	EF 5kt < V_1	Yes	7	3	43%
	23	High	Fire 5kt < V_1	Yes	10	7	70%
	24	High	ASI fail < V_1	Yes	10	7	70%
	25	Inadequate	Fire 5kt < V_1	Yes	9	8	89%

Table 2: Summary of scenarios of the 27 runs.

5 Discussion

The results obtained from the questionnaire and the simulator trials are very indicative of the response that could be expected by the pilot community to the introduction of the Cranfield TOPM display on the flight deck. As the questionnaire was completed after briefing and all the full simulator trials, the volunteers were considered to have a reasonable level of competence in the operation of the instrument that would be reflected by line pilots in the field.

The primary outcome of the questionnaire is that all pilots considered that the instrument would enhance safety and therefore reacted positively to the Cranfield design. A significant majority did not consider the TOPM display to interfere with normal operations, which satisfies the basic design requirement that the instrument should integrate well with current procedure [7]. In unofficial trials, the authors were aware that the TOPM display could be compelling, but were of the opinion that this was mainly due to the novelty of the instrument and that once it became a normal instrument in flight operations, crews would not be attracted by it unnecessarily. This belief was confirmed by the outcome of the questionnaire, where, although 50% claimed to be drawn to the instrument, 83% of these responded that this was because it was a novel display.

One of the requirements defined by the authors during the design of the display was that it should be informative in nature and not executive. The philosophy behind this is that the authors consider the TOPM to be a situational awareness tool aiding the pilot in his decision to continue or abort the run, and not an executive device that would abort the run automatically. All pilots agreed with this approach and their response suggests that the display was interpreted correctly and thus aided them in taking the correct decision.

The questionnaire also clearly underlines the importance of training prior to use. This was expected by the authors. Indeed, as in all cockpit displays, it is crucial that pilots clearly understand what the display is indicating in order to avoid mis-interpretation. Mis-interpretation, in the take-off environment, can lead to inappropriate action and possibly an accident, which would defeat the purpose of the instrument. The authors are of the opinion that the interpretation of the display – particularly in the case of marginal performance – should be an airline SOP in line with guidance interpretation from the manufacturers or authorities. This would reinforce the proper interpretation of the display and reduce the possibility of individual interpretation in marginal conditions.

The simulator results provide further indication of the effectiveness of the TOPM on the flight deck. The decision to abort the run close to V_1 during a real take-off in a field-limited case is always a difficult decision. Indeed, some crews tend to be go-minded, being reluctant to abort a run close to V_1 and prefer to continue even with an engine failure before V_1. This trend can be seen in the results of Run #1, where 27% of pilots continued with an engine failure 10kts before V_1. In comparison only one out of the 11 pilots aborted due to an engine failure just after the decision speed (run #2).

Yet when compared with the pilots' response in identical scenarios with the TOPM, all responded correctly on both occasions, indicating that the TOPM contributes towards the correct decision.

Analysing the runs in different categories with no failure, (runs 3, 6, 10, 13, 16 and 19), the results indicate a high rate of 'correct' actions. It is significant that with inadequate performance, 91% aborted the run, suggesting high value in the instrument in such circumstances. In the improving scenario, where the aircraft performance is initially marginal or inadequate but improves to normal, no pilot aborted the run, whilst with decreasing performance, where the performance is dropping from normal to marginal or inadequate, 7 of the 8 pilots aborted the run. This again is indicative of the value of the performance monitor in such situations. Indeed, the TOPM is expected to be most useful in situations where performance is marginal, inadequate or dynamic. This is where the pilot most needs support and objective indication with respect to performance.

Although the TOPM is not designed to identify engine failures, the evaluation suggests that it can give further confidence to the pilot in taking the correct decision. Indeed, high rates of aborts following engine failures below V_1 are recorded with the use of the TOPM. Two anomalous results are associated with runs 8 and 22 and this may be due to the combination of the pilots' tendency to continue the run coupled with the indication that the achieved performance is well above normal. It is evident that such an indication may further reinforce the said tendency.

In the scenarios with engine failures after V_1, there is no evidence that the TOPM indication discourages continuation of the run when performance is normal or high. However, with marginal, inadequate and dynamic performance conditions, the results suggest that the instrument may encourage crews to abort. The authors are of the belief that in the marginal situation, the crews should not abort the run and this should be addressed in training. It is difficult to assess how appropriate the reactions of the pilots were in the dynamic and inadequate performance scenarios at this stage of evaluation and further investigation is warranted. Indeed, in such situations, the decision to abort without an engine failure is not necessarily an unnecessary abort, since the pilot may prefer not to take the aircraft in the air. This will be down to airline procedures (SOPs) as, in certain circumstances, it may be safer to conduct a high speed abort that would probably result in a low speed overrun rather than take an under-performing aircraft that has just lost an engine into the air. Clearly, this too is an area that requires further investigation.

5 Conclusion

The evaluation carried out has been very successful in providing indications of the potential of the Cranfield display. The results of the questionnaire indicate that all pilots consider the Cranfield TOPM would enhance safety during take-off, whilst the simulator trails suggest that the TOPM should support the crew in taking correct actions. Both the questionnaire and trials also suggest that crews need to be trained for the proper and optimal use of the performance monitor. This suggests that, with such consideration, the instrument should be received a very positively by flying crews and that it should contribute towards greater safety during take-off.

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