مكتب تحقيقات الطيران
Aviation Investigation Bureau

Case Study-2021-001

Investigating Take-Off Performance Occurrences : A Cognitive Approach

Table of Content

Glossary

Abbreviations	
AIB	Aviation Investigation Bureau
ATSB	Australian Transportation Safety Board
BEA	Bureau d'Enquêtes et d'Analyses
CPI	Cognitive Performance Indicators
CSE	Cognitive System Engineering
DGAC	Directorate General for Civil Aviation
EFB	Electronic Flight Bag
FMS	Flight Management System
HTA	Hierarchal Task Analysis
OPT	Onboard Performance Tool
PFD	Primary Flight Display
TOW	Take Off Weight
ZFW	Zero Fuel Weight

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Abstract

Take-off performance occurrences have plagued the aviation industry for years. Numerous safety investigations were conducted to help control and prevent their occurrence. Meanwhile, many technological advancements were implemented. However, these implementations increased overall system complexity and introduced new cognitive constraints and demands on the human operator. Thus, it is necessary for safety investigations (and the investigators conducting them) to be better equipped to address such cognitive complexities in their investigations. A holistic approach is needed when conducting investigations where cognitive complexity may be a concern. Fortunately, the field of human factors enjoys a plethora of tools to address cognitive complexity and help optimize human-system compatibility on a cognitive level.

This paper will utilize such a holistic approach to examine take-off performance occurrences and to propose a potential industry necessity on reviewing the existing take-off performance calculation methodologies/technologies including advanced monitoring and/or warning systems.

A safety investigation concerning a tailstrike occurrence conducted by the Aviation Investigation Bureau (AIB) of Saudi Arabia is examined as a relevant case study. The accident began with a 100-ton Take-off Weight (TOW) discrepancy, which remained undetected and led to subsequent errors. The investigation utilized different human factors tools such as modified Hierarchical Task Analysis (HTA) and Cognitive Performance Indicators (CPIs) to analyze particulars, draw findings, and propose recommendations. Additionally, the history of take-off performance occurrences and key concepts such as cognitive complexity are reviewed and discussed.

Similar Studies

The following section will review and provide a summary of different safety studies conducted by other safety investigation authorities on the topic of take-off performance occurrences some of which were utilized in this study:

Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) - Use of Erroneous Parameters at Takeoff

This study compromised of representatives from three entities, the French civil aviation authority (DGAC), accident investigation agency (BEA), and the Laboratory of Applied Anthropology. The safety study reviewed 12 take-off performance occurrences worldwide, from 1990 through 2006, which were investigated by safety investigation authorities. The study also observed flight operations at two different air carriers and conducted surveys on pilots from within these air carriers regarding their experiences with performance data errors. The study noted that the modern airline pilot no longer possesses a working knowledge of the orders of magnitude of the aircraft’s performance parameters, making it difficult to recognize even a gross data error. The study suggested that training could improve pilot performance and further recommended that pilots be provided with a placard or display incorporating key values for a range of typical conditions. As a result of the safety study, the BEA issued recommendations concerning the design and robustness of procedures and concerning alerting systems. (BEA, 2008).

Australian Transportation Safety Board (ATSB) - Take-off Performance Calculation and Entry Errors: A Global Perspective

This study examines 20 international and 11 Australian take-off performance occurrences, between 1 January 1989 and 30 June 2009. The study provides an analysis of the safety factors that contributed to the occurrences and suggests ways to prevent and detect such errors. The origin of such errors varied from crew actions involving the wrong figure being used, data entered incorrectly, data not being updated, and data being excluded. Furthermore, different contributing factors have been found to contribute to these errors such as systems and devices, including performance documentation, laptop computers, and the flight management computer. The study ensures to emphasize that there is no single solution to prevent or capture such errors and discusses several error capture systems that airlines and aircraft manufacturers can explore to try to minimize the opportunities of take-off performance parameter errors or maximize the chance that any errors that do occur are detected (ATSB, 2011).

Introduction & Overview

Introduction

Take-off performance calculations are a critical element of any flight. Despite, the fact that take-off performance calculations are done in the initial phase of the flight, errors in performance calculations can result in unwanted adverse outcomes such as tail-strikes, runway overruns, and potentially life-threatening accidents. The methodology of calculating aircraft take-off performance evolved from a task that required calculations using tables and charts to a mostly cognitive task, where the role of calculating has been allocated to an Electronic Flight Bag (EFB) or Flight Management System (FMS) (ATSB, 2011). The role of the pilot in the calculation process has been confined to transcribing the required data, monitoring overall system functionality, and the crosschecking between the different sources of data. This shift in workload has reduced the number of steps required (reducing error potential) to complete take-off performance calculations but has created a gap in the crew's awareness making the calculation process less apparent. To the extent that some investigation entities believe the modern commercial transportation pilot lacks working knowledge of an aircraft's performance parameters, thereby hindering their ability to detect even gross data discrepancies (BEA, 2008). Given the cognitive nature of take-off performance calculations, the use of methods and tools common within the field of human factors, to design and enhance human-system interfaces that are cognitively compatible, would be beneficial in their investigation (Hollnagel & Woods, 1983). The objective of this paper is to investigate take-off performance calculations from a cognitive approach. This paper will be divided into two parts. The first part will be an overview of take-off performance occurrences, core concepts, and human factors tools that would be beneficial in the investigation process. Furthermore, it will focus on the concept of cognitive complexity within take-off performance occurrences, and finally the relativeness of cognitive complexity to a safety investigator. The second part will include a take-off performance occurrence case study, a tailstrike occurrence investigation conducted by the Aviation Investigation Bureau (AIB) of Saudi Arabia. The accident began with a 100-ton Take-off Weight (TOW) discrepancy, which remained undetected and led to subsequent errors. Different human factor tools are demonstrated, including the creation of a Hierarchical Task Analysis (HTA) and the use of Cognitive Performance Indicators. The second portion takes all previous sections into considerations and conclude with design recommendations that would better support cognitive work in take-off performance calculations.

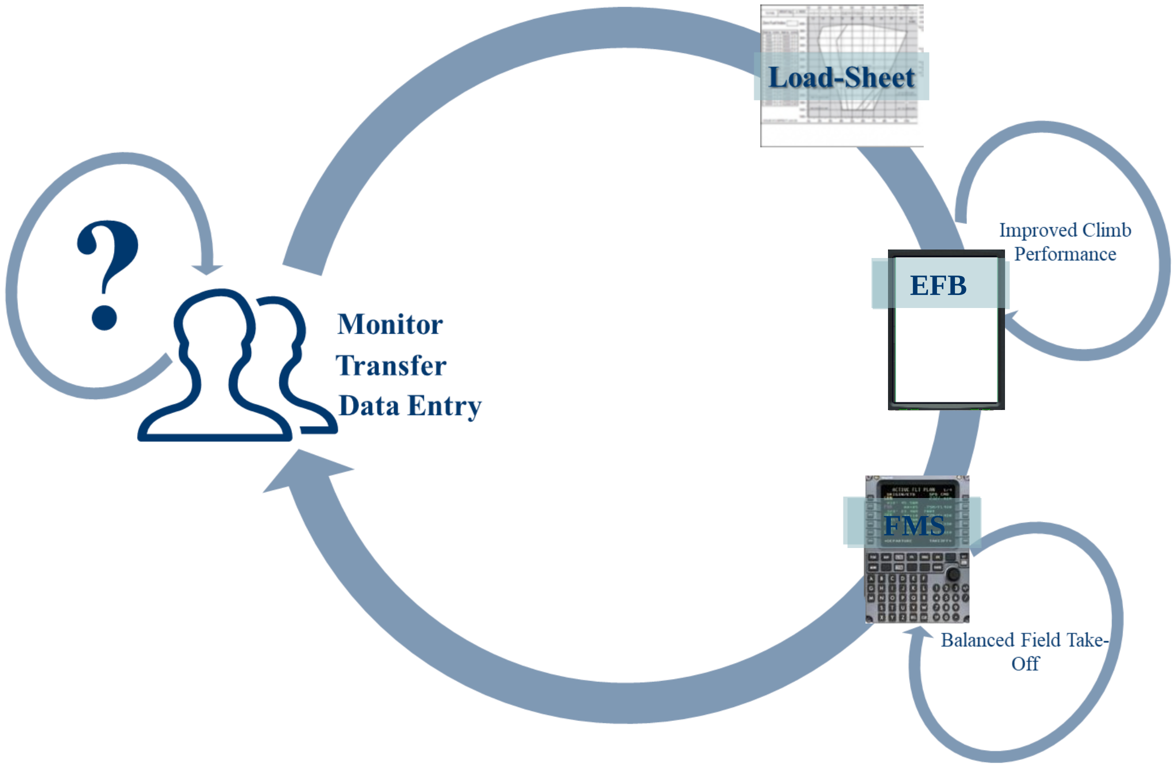
Socio-Technical Systems

Take-off performance occurrences are a particular category of aviation accidents and incidents. An interesting characteristic of take-off performance occurrences is that they are not confined to a specific aircraft or operation type. As previously mentioned, take-off performance occurrences are accidents or incidents that involve the use of incorrect take-off performance parameters (for example: speed, thrust, and weight) to initiate a takeoff. Although, this may seem simple, such occurrences can emerge in various ways (Benard, Nijhof & Van Es, 2019). It is important to understand that in socio-technical systems such as aviation, previous success does not necessarily guarantee future success, given the coupling, complexity, and uncertainty, the different subsystems can interact in an uncontrolled manner that can result in an accident (Dekker & Nyce, 2011). Compare such systems to a Rubik's cube, but imagine certain colored squares are covered in black (representing uncertainty), and for every turn taken by the human, the Rubik's implements a change that the human is not necessarily aware of (representing complexity). Additionally, if the cube is not completed in a certain time duration the human would likely face dire consequences (representing tight coupling). Given the cognitive nature of the take-off performance process and the complexity of sociotechnical systems, the following segments will explain cognitive complexity within take-off performance occurrences, and a few examples of how such occurrences emerge.

Cognitive Complexity

Cognitive Complexity aims to explain cognitive processes in dynamic and complex environments (Schmid, Ragni, Gonzalez & Funke, 2011). Although, this may seem abstract, as previously mentioned, it is relevant to take-off performance occurrences. The take-off performance process transitions from active cognition to passive cognition, and despite it being more reliable and reducing overall error potential, it has had its share of adverse cognitive effects. The different independent automated systems (EFB & FMS) do the majority of calculations; the crew's involvement is narrowed to monitoring functionality, inputting data, and transferring data between the independent data sources (FMS, EFB & load-sheet). Additionally, these independent systems (EFB & OPT) can have different cognitive models. For example, the EFB's take-off performance calculation application might be designed based on the concept of improved climb performance to preserve engine life and increases allowable maximum take-off weight, taking such factors into consideration when calculating. On the other hand, the FMS might be designed based on a balance field take-off concept and not address such factors creating a variation in their cognitive models. This lack of crew engagement and the complexity in the calculation process has resulted in the issue of passive cognition, where flight crew members are less likely to remember and manipulate the readily provided take-off parameters. Passive cognition has been shown to adversely affect other cognitive processes such as situation awareness (Endsley, 2016). This has created other adverse effects where crew members are no longer able to build mental models of take-off performance parameters in relation to speed and weight (such as a ballpark number for take-off speed, thrust, and flap setting appropriate for an aircraft close to maximum take-off weight) (Berman, Dismukes & Jobe, 2012). See Figure 1, for crew engagement in take-off performance calculation process.

Figure 1: ***Engagement in Take-off Performance Calculation Process***



To further emphasize the complex and dynamic nature of the environments that these cognitive processes occur in, the various manners in which such occurrences emerge is discussed. A study conducted by Benard, Nijhof & Van Es (2019) reviewed 49 different take-off performance occurrences that occurred from 1998 to 2018. The study revealed that such occurrences can emerge from different circumstances, and a subset of the occurrences included circumstances regarding aircraft weight. For example, using the Zero Fuel Weight (ZFW) instead of the Take-Off Weight (TOW) for the calculations, using the landing weight for take-off calculations, and using weight of 10 or 100 tons below actual weight. Other take-off performance occurrences included the use of low thrust settings and using incorrect runway distance for calculations, especially when taking off from an intersection. See Table 1 for the history of take-off performance calculations and their different circumstances.

Table 1: **Take-Off Performance Occurrences from 1998 to 2018 (Benard, Nijhof & Van Es, 2019).**

Type Take-off Performance Occurrences	No. of Occurrences from 1998 to 2018
Take-Off performance based on ZFW	12
Take-Off performance based on landing weight	2
Take-Off performance based on 10 or 100 tons below actual take-off weight	10
Take-off performance calculated by dispatch (not by crew)	3
Take-off with lower thrust setting	6
Take-off performance with incorrect runway distance	15
Overall Take-Off Performance Occurrences	49

Given the cognitive role where the flight crew are responsible for transferring data between different sources, crosschecking such data, detecting discrepancies, and the overall complex nature of the environment they operate in, it is safe to say that the current predicament is less than ideal. In other words, the flight crew are required to utilize cognitive functions to complete their work, but the systems they manage do not optimally support these cognitive functions. To the extent that the modern airline pilot has a limited mental model of take-off performance parameters in relation to the aircraft. Such a predicament is a reminder to safety investigators that a holistic view is needed when conducting investigations where cognitive complexity may be a concern, as new solutions can mean new problems. Fortunately, the field of human factors has a plethora of tools to address cognitive complexity and help optimize human-system compatibility on a cognitive level. The following segment discusses the different tools available that may aid in achieving such an objective in an investigation.

Tackling Cognitive Complexity in Accident Investigations

As previously mentioned, many tools are available to address the increased complexity of systems and their adverse effects on cognition. The overall objective of such tools, common in the field of human factors and Cognitive System Engineering (CSE) is to ensure the system supports, enhances or optimizes cognitive work and to facilitate optimal cognitive compatibility (Hollnagel & Woods, 1983). On the other hand, safety investigations are tasked with investigating accidents to prevent and control their occurrence, such investigations might occur in sociotechnical systems where cognitive complexity must be addressed to fulfill the objective of prevention or control. As such, overlap exists between the different fields. Below, is a brief description of different tools that would benefit the investigation process:

Hierarchical Task Analysis: The HTA takes a reductionist view of work. The HTA decomposes complexity to its bare components to better understand how people interact within their working environments. The HTA focuses on the tasks needed to fulfill the objective of the system and the plans that entail the methodology of achieving the identified tasks. Furthermore, the identified plans direct the order of which subtasks are best completed. A holistic grasp of the goals, tasks, plans, and subtasks are mandatory for the successful application of an HTA and are commonly illustrated in tables and flowcharts (Sarker, Chang, Albrani & Vincent, 2007). What makes HTA a staple analysis within the field of human factors is its flexibility and adaptability. Furthermore, the user is able to describe and assess the goals, functions, and tasks to the degree that best fits the problem being analyzed. A key feature of such flexibility is the ability of using HTA as a foundation for further analysis, it is such flexibility that facilitates the use of HTA in safety investigations (Lane, Stanton & Harrison, 2006). Investigators are limited by time, resources, available evidence, the perishable nature of evidence, lack of training to implement such systemic approaches, and are governed by regulatory framework that might make the tackling of more complicated methods less motivating (Underwood & Waterson, 2013). The fact that the scope of HTA could be adjusted depending on the resources available and its ability to facilitate the use of further analysis methods opens different opportunities depending on the nature of the occurrence. For example, the HTA could be tailored to address different team members, the physical resources needed to complete the tasks, and address cognitive performance indicators (will be discussed later).

Cognitive Performance Indicators: Cognitive Performance Indicators are used to assess how a system can support or hinder cognitive work. Cognitive Performance Indicators have seen success in analyzing naturalistic contexts (such as aviation) where the human operator is required to make decisions under uncertainty and assess situations for discrepancies (Wiggins & Cox, 2010). The number of cognitive indicators can vary and change depending on the nature of work being analyzed, but there are 11 common indicators. The indicators can be distributed into 2 groups, 7 of which fall under the situation assessment group, while the remaining 4 indicators fall under the execution group (see Table 2 for a brief description of each indicator). It has been argued that cognitive indicators lack structure and are ineffective as a standalone analysis. The ease of use of Cognitive Performance Indicators may be beneficial to investigators who may lack the domain knowledge of human factors or CSE and would be a viable tool in any investigation where cognitive issues may be a concern.

Table 2: **Cognitive Performance Indicators Table (Wiggins & Cox, 2010).**

Cognitive Performance Indicators			
Situation Assessment Group		Execution Group	
Indicator	Description	Indicator	Description
Cue Prominence	Allows the user to easily locate cues from displayed information.	Workability	Allow the user to determine if the option is workable.
Situation Assessment	Support users to form their own assessment and independent work.	Directabillity	Support the directing/redirecting of priories to adapt to changing situations.
Transparency	Allow access to system data and how the system	Adjustability	Allow users to adjust system settings.

	arrived to processed data.		
Direct Comprehension	Allow users to directly comprehend cues without further processing/calculating.	Procedural Flexibility	Allow flexibility in the order of procedures as the situation demands.
Fine Distinction	Allow access to unfiltered data when needed.		
Historic Information	Support capture of historic information to facilitate assessments.		
Enable Anticipation	Provide information that allows the anticipation of future states.		

Case Study

The following portion implements the previously mentioned human factors tools to investigate a take-off performance occurrence case study. The case study is a tailstrike occurrence concerning a Boeing 747 conducted by the Aviation Investigation Bureau (AIB) of Saudi Arabia. The accident began with a 100-ton Take-off Weight (TOW) discrepancy to calculate the take-off speeds using the Onboard Performance Tool (OPT). The error remained undetected, bypassing all crosschecks and system controls, led to subsequent errors, and ultimately contributed to the tailstrike. The case study only examines the portions related to the take-off performance calculation process and does not cover other aspects such as decisions made after the tailstrike or regulatory/organization factors. The majority of the information used to implement the human factor tools were gathered during the investigation process. Additionally, two technical advisors with substantial experience on same aircraft type were utilized throughout the process. The first step utilizes the above-mentioned resources to conduct a modified HTA. Using the HTA as a basis, cognitive performance indicators and the actual circumstances of the occurrence are implemented to identify certain cognitive issues.

Step 1: Hierarchical Task Analysis (HTA)

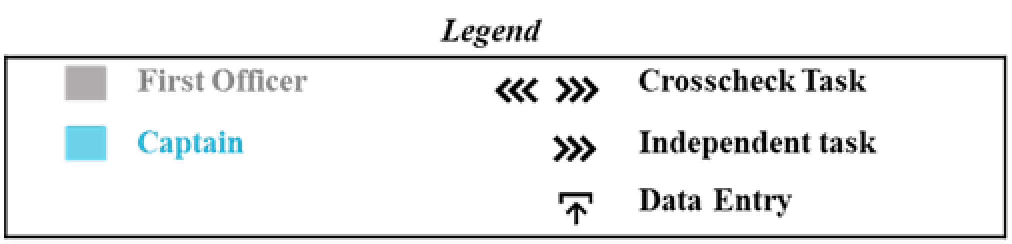
The HTA takes a reductionist view of work to better understand how people interact within their working environments (Sarker, Chang, Albrani & Vincent, 2007). As such, this analysis does not include the variability and circumstances that transpired in the occurrence (this is tackled in step 2). The HTA encompasses how the plans, tasks, and subtasks needed to fulfill the system's objective prior to the occurrence. Additionally, the HTA has been modified to address different team members, the physical resources needed to complete the tasks, and the different type of tasks (independent task, crosscheck task and data entry). The following are brief summaries of some the resources (OPT and FMS) required for the crew to complete the take-off performance process:

- FMS: Uses the calculated gross weight (an addition of the weight of the actual fuel and the ZFW) for the calculation of the take-off reference speeds. This zero-fuel weight has to be inserted in the FMS while the fuel weight is sensed automatically by the aircraft system. Speeds generated from the FMS do not account for improved climb performance or the use of unbalanced field lengths (e.g. clearway and /or stopway distance credit). In addition, the speeds do not account for non-normal conditions such as anti-skid inoperability, brakes deactivated or contaminated runway conditions. Speed adjustments for these conditions must be determined from other sources.

- OPT: An EFB-based application based on the concept of improved climb performance not on a balanced field Take-off concept as used in the FMS, to preserve engine life and increases allowable maximum take-off weight. The operator adopted Boeing OPT as the primary method to calculate take-off and landing performance data and for the selecting of optimum thrust and flaps when using the OPT.

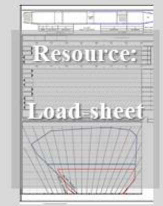
Utilizing the information gathered from the investigation and the technical advisors, three main tasks were identified for the take-off performance calculation process. The first task is the Flight Management System (FMS)-load sheet setup, which requires the review of the load sheet and transcribing data into the FMS. The second task are the independent Onboard Performance Tool (OPT) calculations where crew members perform independent OPT calculations (OPT is a calculation software in the EFB). The final task consists of calculating take-off speeds via FMS, OPT, and checking speeds on Primary Flight Display (PFD). See figure 1 for full HTA analysis.

Figure 2: ***HTA of Take-Off Performance Occurrence Case Study***



Plan
Do Subtasks 1.1, 1.2, 1.3, 1.4, 1.5 during crosscheck tasks (1.4 & 1.5) if any discrepancies occur conduct recovery action (1.6) and return to subsequent order

1.0 Load Sheet & FMS Setup



1.1 Review and sign the Load-sheet then hand it over to the FO »» **1.2** Read out ZFW »»

1.3 Enter ZFW into FMS ↑ »»

1.4 Read out Gross fuel weight from FMS «« »» Confirmed on load-sheet

1.5 Read out take-off weight «« »» Confirm on load-sheet

Recovery & Remedial Actions

1.6 If discrepancy between FMS and load-sheet occurs during crosscheck tasks repeat task till values are within range of one another and return to subsequent order

Plan
Do subtasks 2.1, 2.2, & 2.2, subsequently. In case of discrepancies during task 2.3 conduct task 2.4 and continue

2.0 OPT Calculations

2.1 Enter required values into OPT »» ↑ **2.2** Enter required values into OPT »» ↑

2.3 Read out OPT parameters «« »» Confirm OPT parameters are identical

Recovery & Remedial Actions

2.4 If discrepancy between Captain and First Officer EFB calculations occur, repeat from 2.1 to ensure equivalency and continue

Plan
Do subtasks 3.1, 3.2, 3.3 subsequently. In case of discrepancy during task 3.3, repeat 3.2. conduct task 3.4

3.0 OPT – FMS Speed Calculations

3.1 Enter required OPT take-off parameters into FMS for FMS to calculate Take off speeds »» ↑

3.2 Enter the OPT calculated speeds into the FMS »» ↑

3.3 Crosscheck Speed values on PFD are identical to FMS «« »» Crosscheck Speed values on PFD are identical to FMS

Recovery & Remedial Actions

3.4 If values entered into FMS and displayed on PFD are not Identical repeat task 3.3 till required results are achieved

Step 2: Cognitive Performance Indicators and Variability

The HTA as a standalone tool may be ill suited to capture the complexity of sociotechnical systems. Fortunately, its flexibility allows for further analysis tools to be utilized. This step will add the variability that transpired in the occurrence. During task 2 (OPT calculations) the procedure specifies that each pilot enters the data independently, the entered data is compared and then the results of the calculations are compared. The effectiveness of such a crosscheck was reduced by the verbalization of an erroneous value by the captain to the first officer. The first officer read out 273 tons instead of 373 tons, both the captain and first officer used the same incorrect weight for the OPT calculation (the take-off weight in the FMS during task 1 was correct and the crew were aware that the aircraft was heavy). During task 3, the crew entered the incorrect OPT calculated take-off parameters (flaps, temperature, and thrust) based on a 100-ton discrepancy into the FMS. Subsequently, the FMS was unable to calculate its own take-off speeds (the parameters entered did not match the correct take-off weight which was calculated during task 1 and displayed dashes). The crew rechecked to see that all FMS entries were available but not correct and tried again. The problem persisted and the crew continued to enter the incorrect OPT speeds into the FMS, the error remained undetected and was used for take-off. In addition to the circumstances of the accident, cognitive performance indicators (the 11 mentioned in part 1) will be implemented on the HTA (only task 2 and 3 will be included) to identify potential cognitive hindrances within the system. The analysis is confined to identifying the conditions that impede cognitive functions. See figure 2 for HTA with added circumstances and cognitive performance indicators.

Figure 3: **HTA Analysis (task 2 and 3) of Take-Off Performance Occurrence Case Study Including Cognitive Performance Indicators and Circumstances of the Occurrence.**

Plan
Do subtasks 2.1, 2.2, & 2.2, subsequently. In case of discrepancies during task 2.3 conduct task 2.4 and continue (No discrepancies as both crewmember used same values)

2.0 OPT Calculations

100 tons discrepancy

2.1 Entered erroneous values into OPT »» ⭱

2.2 Entered erroneous values into OPT »» ⭱

2.3 Read out incorrect OPT parameters «« »» Confirmed incorrect OPT parameters were identical

! Cognitive Performance Indicators

Situation Assessment The operator's procedures specified that the calculation needed to be independent but a verbal exchange between crewmembers eliminated the independency and limited their ability to build situation assessment.

Plan
Do subtasks 3.1, 3.2, 3.3 subsequently. In case of discrepancy during task 3.3, repeat 3.2. conduct task 3.4

3.0 OPT – FMS Speed Calculations

3.1 Entered erroneous OPT take-off parameters into FMS for FMS to calculate Take off speeds »» ⭱

FMS could not calculate T/O speeds - FMS displayed dashes ------

3.2 Rechecked FMS entries for availability and entered the OPT erroneous speeds into the FMS »» ⭱

3.3 Crosscheck Speed values on PFD are identical to FMS «« »» Crosscheck Speed values on PFD are identical to FMS

! Cognitive Performance Indicators

Directabillity The operator's procedure did not provide guidance or explanation in case the FMS does not calculate its own T/O speeds.

Situation Assessment The operator's procedures did not require a final crosscheck between the FMS , OPT, and load sheet

Directabillity The FMS does not provide an alerting message why the performance calculation is inhibited.

Transparency and Cue Prominence The FMS did not highlight the erroneous TO in any form nor warned of the loss of protection against entering speeds which are too low

Step 3: Discussion

Using Cognitive Performance Indicators on the previous analysis, 4 different findings were drawn, 3 of the findings fell under the situation assessment group and 1 from the execution group. In task 2.0, an issue impeding situation assessment was identified. Although, the procedures require the calculations to be independent, the context where pilots are accustomed to working together as a crew with verbal exchanges hinders their ability to perform calculations separately but yet side by side. A simple verbalization can make this barrier fallible. It is imperative to support cognitive work; the crew members need to be able to form their own assessment, but the lack of independency may deprive the crew from opportunities of situation assessment (Wiggins & Cox, 2010). In task 3.0, multiple findings were identified. In the execution group there were issues in directabillity, the operator's procedures did not give any guidance on what to do when the FMS does not calculate its own speeds. Subsequently, the crew continued as planned an entered the erroneous OPT calculated speeds into the FMS. Additionally, the FMS does not direct the crew to why the speeds were not calculated and only display dashes. It is imperative that support is given to direct or redirect priorities to adapt to change and uncertainty (FMS not providing take-off speeds) (Wiggins & Cox, 2010). Situation assessment was again identified in task 3.0, the operators' procedures do not require a final take-off crosscheck between independent sources (FMS, OPT, and load sheet), depriving the crew from an independent assessment. The final 2 findings were under the situation assessment group (transparency and cue prominence). As previously mentioned, due to issues in passive cognitive it is no longer enough to just have the discrepancy available for it to be detected. After the FMS did not provide its speeds, the crew reviewed all entries but were unable to detect the discrepancies based on a 100-ton lower weight (despite the fact they discussed that the aircraft was heavy). Additionally, the crew when entering the erroneous OPT speeds into the FMS were unable to detect that the relatively low speeds were insufficient for the weight of the aircraft. In the context of high cognitive work demands, it is imperative that the system makes prominent cues more observable and be transparent on how they arrive to processed data (Wiggins & Cox, 2010).

Step 4: Recommendations

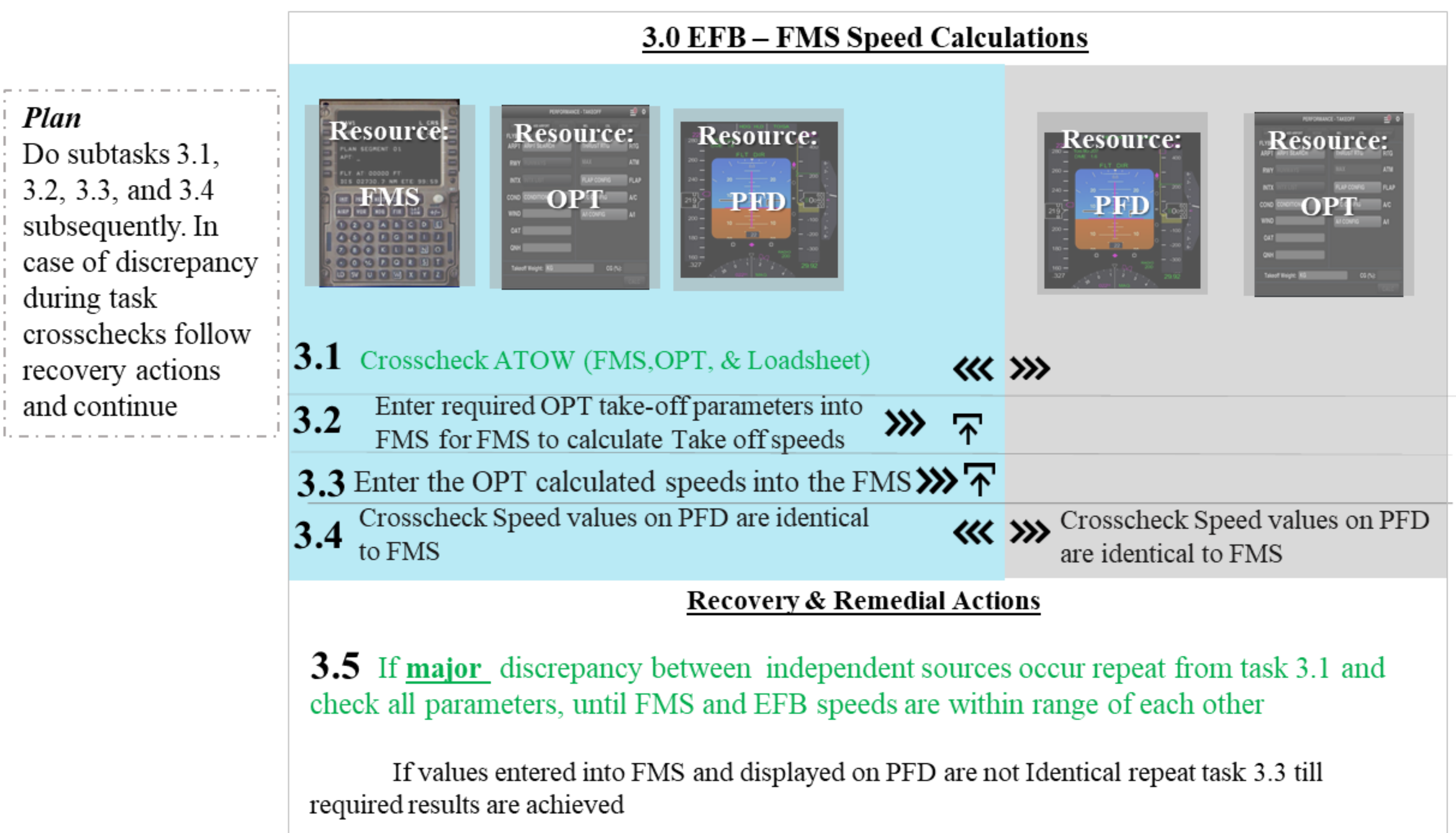
Based on the previous analysis, the following recommendations are proposed:

1. For the operator, to require that prior to entering the OPT calculated speeds into the FMS (task 3) the crew conduct a final crosscheck between the different sources (OPT, FMS and load-sheet), having a crosscheck in both task 2 and 3 or after could better facilitate situation assessment.

2. For the manufacturer, to study the feasibility of establishing a take-off performance monitoring system (TOPMS) that would provide flight crews with an accurate and timely indication of inadequate take-off performance.

The proposed amendment to add a final crosscheck was applied on the HTA. See Figure 4 for proposed amendments.

Figure 4: **HTA Analysis with Amendments.**



The recommendation was accepted by the operator, adding a final crosscheck between the TOW of the OPT, FMS, and loadsheet within their "Before Start Checklist". Additionally, the recommendation addressed to the manufacture was "to study the feasibility" of implementing system design changes in to increase detectability, transparency, and cue prominence due to the fact that further analysis and examining is needed to fully assess the viability of such a design change. When investigating sociotechnical systems, it is important to remember that new solutions can mean new problems. The last thing desired from any safety recommendation is to create the opportunity for another accident or incident. Other safety investigation authorities have identified similar safety concerns when investigating take-off performance occurrences. The following section will review a similar occurrence prior to presenting the conclusions.

Similar Occurrence

BEA - Serious incident involving Boeing 777-F on 22 May 2015 at Paris - Charles-de-Gaulle Airport

A Boeing 777F operated by Air France on a scheduled cargo flight from Paris CDG to Mexico City commenced with low thrust set for a take-off weight (TOW) of 243 tons instead of the actual weight of 343 tons. Automatic activation of the tailstrike protection system during rotation was followed by the application of full thrust in response to one of the Relief Pilots calling out TOGA .

Similar to the presented occurrence, the independency of the crosscheck was likely deprived due to the verbalization of the incorrect TOW prior to the OPT calculations, this aspect was covered in the analysis of the investigation. As a result, the erroneous value was the same for both crew members and made this barrier fallible, the crew were unable to form their own assessment. Additionally, The FMS directabillity and transparency were a factor. The displayed speeds unavailable message does not specify why the speeds are inhibited or provide information about the consequences.

The Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA) recommended the operator to increase robustness of the crosschecking procedures and add a final crosscheck between all independent data sources. The BEA also recommended the manufacturer to include more effective systems that offers warnings and protection against to the use of erroneous speeds (BEA, 2019).

Conclusions

The objective of this paper was to investigate take-off performance occurrences which are a specific group of accidents and serious incidents where suboptimal cognitive compatibility between the different agents have been repeatedly identified. The history and circumstances of take-off performance occurrences were reviewed using safety studies, accident reports and human factor literature. Additionally, a case study was conducted on a take-off performance occurrence where different tools were used to analyze the serious incident, draw findings, conclusions and propose recommendations to control its reoccurrence. The field of human factors has many tools to offer that would add value to any investigation where cognitive complexity may be a concern.

The following are some of the common concerns identified in take-off performance occurrences:

1. The lack of crew engagement in the calculation process has resulted in the issue where flight crew members are less likely to remember and manipulate the readily provided take-off parameters.
2. The take-off performance calculation process requires the transfer and monitoring of information between different independent sources (FMS, EFB, and load-sheet) to calculate parameters thus increasing the potential for error.
3. In many of the occurrences, the cross-checking procedures were not robust enough to detect erroneous entries and their implications on the take-off performance calculation process.
4. Current aircraft systems do not alert the crew of erroneous parameters and the provided indications/messages do not direct the crew to why the speeds were not calculated or provide information about the consequences.

It is important to note, due to the nature of cognitive processes in dynamic and complex environments, there is no one solution to prevent such errors from occurring or capturing them after they occur. A promising solution is the inclusion of a take-off performance monitoring system (TOPMS) that would provide flight crews with an accurate and timely indication of inadequate take-off performance. Further analysis and examining is needed to fully assess the optimal method of integrating such system to prevent the emergence of new concerns.

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