European Union Aviation Safety Agency

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RESEARCH PROJECT EASA.2022.HVP.01

D-1.1 REVIEW OF EXISTING LITERATURE AND IDENTIFICATION OF DIGITAL SOLUTIONS

Digital transformation - Case studies for aviation safety standards - Data Science Applications (DATAPP)

An Agency of the European Union

Disclaimer

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SUMMARY

Problem area

Digitalisation is reshaping the aviation business at quick pace, bringing efficiency and wider opportunities to manage information. The deployment of digital solutions throughout the air transport industry is a fact and brings significant changes to the traditional working processes, business models, standards, and regulations.

EASA faces new challenges on what the required changes in safety standards and regulations are needed in response to the introduction of innovative solutions and processes. Anticipating what is to come in the industry in the field of data science applications is key to make sure safety levels are maintained without slowing innovation down.

The objective of this project is to identify and assess relevant changes to the existing aviation safety standards in order to support the deployment of the digital solutions under three case studies:

- Case Study 3: Flight training data for EBT/CBTA (Evidence-Based Training / Competence-Based Training and Assessment)
- Case Study 4: Digital fuel management
- Case Study 5: Flight data models for safety

The project aims to provide a comprehensive evaluation of benefits, constraints, standardisation, and deployment issues, including the recommendations for adjusting safety regulations and related standards, and how new digital technologies could contribute to addressing the identified issues.

Description of work

The present document is ‘D-1.1 Review of existing literature and identification of digital solutions’ of “DATAPP (Digital Transformation – Case Studies for Aviation Safety Standards – Data Science Applications)” project (EASA.2022.HVP.01- Horizon Europe Project). It provides an overview of the current regulatory framework of each of the Case Studies under the scope of the project. In addition, the document presents a set of digital solutions relevant for the fields under study, settling the baseline for the next steps of the project for each case study development.

Results and Application

The literature review of relevant documentation within the topic of each Case Study under the scope of the project has allowed to identify the current situation in terms of regulatory framework and available digital solutions on the market. The literature has shown that data usage and digitalisation have been already embraced by the aviation community, but there is need for guidelines definition and standardisation for data identification, collection, integration, storage, and protection. Digital solutions are being introduced into many processes and operations procedures, but their adoption still requires new technical standards and guidance to ensure the standardisation, integration and fusion of data sources in the aviation safety ecosystem, as well as the effective protection and management of data and its adaptation to the safety requirements of the aviation sector. The challenges identified in this document together with the digital capabilities and solutions define the context in which the case studies will be developed in the next steps of the project.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
AC	Advisory Circular
ACARS	Aircraft Communication Addressing and Reporting System
ACSF	Air Charter Safety Foundation
ADS-B	Automatic Dependent Surveillance Broadcast
AESA	Agencia Estatal de Seguridad Aérea
AFM	Aircraft Flight Manual
AHM	Aircraft Health Management
AI	Artificial Intelligence
AltMoC	Alternative Means of Compliance
AMC	Acceptable Means of Compliance
AMM	Aircraft Maintenance Manual
ANN	Artificial Neural Network
ANSP	Air Navigation Service Provider
AOC	Air Operator’s Certificate
APU	Auxiliary Power Unit
ASIAS	Aviation Safety Information Analysis and Sharing
ASR	Annual Safety Review
ATC	Air Traffic Control
ATS	Air Traffic Service
BI	Business Intelligence
BI	Business Intelligence
C.F.R.	Code of Federal Regulations
CAT	Commercial Air Transport
CBTA	Competency-Based Training and Assessment
COTS	Commercial Off-The-Shelf
CS	Case Study
CVR	Cockpit Voice Recorder
D4S	Data4Safety
DG MOVE	Directorate-General for Mobility and Transport
DGAC	Direction Générale de l'Aviation Civile
EAFDM	European Authorities Coordination Group on Flight Data Monitoring
EASA	European Union Aviation Safety Agency
EBT	Evidence-Based Training
ED	Executive Director
EFB	Electronic Flight Bag
ELM	Extreme Learning Machine
EOFDM	European Operators Flight Data Monitoring forum

ACRONYM	DESCRIPTION
EPAS	European Plan for Aviation Safety
ERA	En-Route Alternate
EU	European Union
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDAP	Flight Data Analysis Programmes
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FDX	Flight Data Exchange
FOQA	Flight Operations Quality Assurance
FRF	Final Reserve Fuel
FSF	Flight Safety Foundation
FSTD	Flight Simulator Training Device
GA	General Aviation
GADM	Global Aviation Data Management
GBM	Gradient Boosting Machine
GM	Guidance Material
GMM	Gaussian Mixture Model
GPS	Global Positioning System
HDBSCAN	Hierarchical Density-based Spatial Clustering of Applications with Noise
HFDM	Helicopter Flight Data Monitoring
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICAP	Instructor Concordance Assurance Programme
IFALPA	International Federation of Air Line Pilots' Associations
ITQI	IATA Training and Qualification Initiative
JAA	Joint Aviation Authorities
JAA	Joint Aviation Authorities
KNN	K-Nearest Neighbour
KPI	Key Performance Indicator
LFL	Logical Frame Layout
LOF	Local Outlier Factor
LPC	License Proficiency Check
MAE	Mean Absolute Error
MARS	Multivariate Adaptive Regression Splines
METAR	Meteorological Aerodrome Report
ML	Machine Learning
MOR	Mandatory Occurrence Report
MRO	Maintenance, Repair and Overhaul

ACRONYM	DESCRIPTION
MST	Member States Task
MTOW	Maximum Take Off Weight
MWL	Most Wanted List
NAA	National Aviation Authority
NBAA	National Business Aviation Association
NOTAM	Notice To Airmen
NTSB	National Transportation Safety Board
OB	Observable Behaviour
OCC	Operator Control Capability
OD	Origin-Destination
OEM	Original Equipment Manufacturer
OIG	Office of Inspector General
OJEU	Official Journal of the European Union
OPC	Operator Proficiency Check
OPS	Operations
PFD	Primary Flight Display
PNR	Point of No Return
QAR	Quick Access Recorder
RF	Random Forest
RMT	Rule Making Task
RSI	Relevant Safety Information
SaaS	Software as a Service
SAFE	Safety in Aviation Forum for Europe
SATCOM	Satellite Communications
SCF	Statistic Contingency Fuel
SMS	Safety Management System
SOP	Standard Operating Procedure
SPI	Safety Performance Indicators
SSR	Secondary Surveillance Radar
ToR	Terms of Reference
UK	United Kingdom
USA	United States of America
USDOT	United States Department of Transportation
VHF	Very High Frequency

1. Introduction

1.1 Background

Digitalisation is reshaping the aviation business at quick pace, bringing efficiency and wider opportunities to manage information. The deployment of digital solutions throughout the air transport industry is a fact and brings significant changes to the traditional working processes, business models, standards, and regulations.

In its role of EU Aviation Safety Regulator, EASA faces new challenges on what the required changes in safety standards and regulations are needed in response to the introduction of innovative solutions and processes. Anticipating what is to come in the industry in the field of data science applications is key to make sure safety levels are maintained without slowing innovation down. For that, identifying the key main applications in that area in the form of case studies, allows to better picture ourselves in what is to come and will allow translating that future into recommendations for standardisation and regulations.

This project aims at evaluating a series of changes applied to aviation products, processes and operations resulting from the deployment of new digital solutions with a focus on measuring the impact on safety standards and regulatory materials as well as to prepare their evolutions. The project is built upon three case studies allowing to develop a comprehensive investigation of the key changes at stake:

- Case Study 3: Flight training data for EBT/CBTA. The case study will encompass the development of comprehensive guidelines for moving towards the implementation of EBT and CBTA concepts.
- Case Study 4: Digital fuel management. The project will encompass the in-depth analysis of the benefits and constraints associated to state-of-the-art digital solutions for fuel management, considering the current safety issues reported, as well as the preparation of comprehensive documentation to support the proposed evolution of standards and regulatory requirements.
- Case Study 5: Flight data models for safety. The proposed case study will investigate the development of comprehensive data models 'bridging' between the flight data sources and their use for the operator's safety-relevant processes and for industry-wide data exchange programmes.

The development of these case studies will lead to the identification of key actions to be taken by safety regulators, service and solution providers to streamline the deployment of such innovative digital applications.

1.2 Scope of the report

This report represents deliverable 'D-1.1 Review of existing literature and identification of digital solutions' of "DATAPP (Digital Transformation – Case Studies for Aviation Safety Standards – Data Science Applications)" project (EASA.2022.HVP.01- Horizon Europe Project). It provides an overview of the current regulatory framework of each of the Case Studies under the scope of the project. In addition, the document presents a set of digital solutions relevant for the fields under study, settling the baseline for the next steps of the project for each case study development.

The present document is structured as follows:

- Section 1 consists of an introduction presenting the background of the project, the scope of the document and the methodology followed to develop the literature review.
- Section 2 describes the context, regulatory framework, digital capabilities, solutions and conclusions for Case Study 3 Flight training data for EBT/CBTA.
- Section 3 describes the context, regulatory framework, digital capabilities, solutions and conclusions for Case Study 4 Digital fuel management.

- Section 4 describes the context, regulatory framework, digital capabilities, solutions and the conclusions for Case Study 5 Flight data models for safety.
- Section 5 gathers the conclusions extracted from the review of relevant documentation in each case study.
- Section 6 presents the next steps to be taken, settling the direction of the case study work plan definition.
- Bibliography collects the reference list of all consulted documentation during the preparation of the literature review.

1.3 Applied methodology

The understanding of the context of each case study under the scope of the project is crucial to undertake the assessment of changes in aviation resulting from the deployment of new digital solutions. As this document aims to settle the baseline for the development of the case studies, an exhaustive literature review has been completed in the field of pilot EBT/CBTA, fuel management and flight data monitoring. The methodology followed is presented in Figure 1-1 below, which reflects the structure of the results presented in section 2, 3 and 4 for each case study.

Figure 1-1 Literature review methodology

Introduction
- Context of the case study and historical evolution
- Description of the concepts and existing programmes
- Identification of stakeholders
- Understanding of the need of use of data

Overview of regulatory framework
- List of consulted documentation and regulations
- Understanding of the regulatory framework, highlighting the structure and key requirements for programme implementation

Digital capabilities and solutions
- Grouping of supporting tools based on the regulatory framework
- Identification of areas that can benefit from the use of data
- Identification of available digital capabilities, identifying commonalities and specific characteristics
- Overview of current digital solutions available on the market and under research

The outcome presented in this document provides a deep understanding of the case studies context, describing the regulatory framework and focusing on the digital capabilities and the existing solutions based on data usage. The maturity of the digitalisation phase within each case study is reflected by the evolution of the regulations in line with innovation, the capabilities offered by the industry and the topics under research to respond to the emerging stakeholder needs.

The identified digital capabilities are structured in line with the requirements defined by the regulations and give a hint on the need for change of the regulatory framework to adapt to the new technologies. This allows understanding the challenges within each case study and the affected stakeholders to be considered in the case study work plan in the next steps of the project.

2. Case Study 3: Flight training data for EBT/CBTA

2.1 Introduction

Over the past decades, major advances in aircraft technology and systems have translated to an evolving environment within which aircraft operate. Despite aircraft's configuration and navigational systems changing accordingly, **pilot training has remained largely unchanged**. For over forty (40) years, pilot training has been performed in the form of **repeated tasks and manoeuvre-based practices** identified as those that have historically contributed to accidents or incidents. These significant changes in the operating environment have brought new operational challenges, to the extent that repetitive training methodologies are no longer meeting the needs of airline pilots.

In this context, the aviation industry realised that pilot training needed a shift in its approach and in 2007 settled the International Air Transport Association (IATA)'s Training & Qualification Initiative (ITQI) initiated by Airbus and developed by IATA. The **evidence-based training (EBT)** concept was developed in collaboration with International Civil Aviation Organization (ICAO) and the International Federation of Air Line Pilots' Associations (IFALPA). ICAO Doc 9995 "Manual of Evidence-Based Training" [1] was published to provide guidance in the implementation of this new, more effective training to improve operational safety. IATA defines EBT as the *"training and assessment characterized by developing and assessing the overall capability of a trainee across a range of competencies rather than by measuring the performance of individual events or manoeuvres"*. In essence, EBT is a pilot training concept centred on the principles of **competency-based training and assessment (CBTA)**, which is characterized by its performance orientation. **EBT is a CBTA programme that uses specific training topics as vehicles to develop the pilot competencies.** CBTA is applicable to all spectrum of pilot training from pilot aptitude testing, pilot initial licensing training, Instructor/Evaluator training and operator training, while EBT is a CBTA programme currently applicable to pilot recurrent training only.

The global safety initiative for pilot training aimed to **identify the competencies required to operate safely (CBTA) whilst addressing the most relevant threats according to evidence collected in data (EBT)**. To do so, an extensive data analysis was conducted by IATA that considered evidence from multiple sources, including monitoring of regular operations, flight data monitoring and reporting programmes. The results of this analysis are summarised in IATA's Data Report for Evidence-Based Training (2014) [2]. In addition, EASA started working on the new set of rules for EBT that would allow a **progressive implementation of EBT in which operators would gradually move from a traditional task-based system towards a new competency-based training system**. The first step in the context of European Union rulemaking actions was completed in 2015 with the publication of **ED Decision 2015/027/R** [3], which provided guidance material to allow the implementation of a **Mixed EBT**, a programme that involves the dedication of part of the periodic assessment and training to the implementation of EBT.

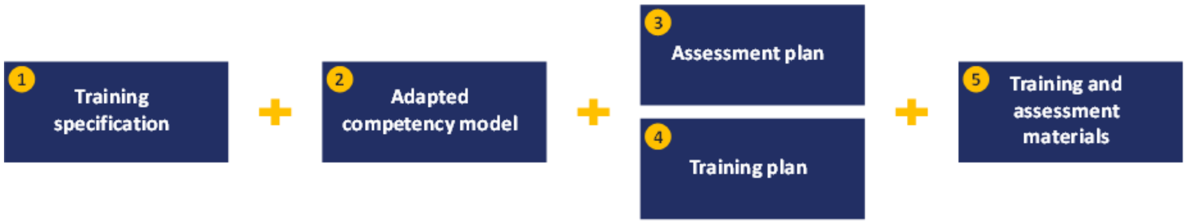
In 2016, EASA published the ToR for RMT.0599 'Evidence-based and competency-based training' [4], to regulate **Baseline EBT**. This publication aimed to align the European regulation with ICAO Doc 9995 and to provide continuity to the path already proposed. Finally, in 2021, EASA published **ED Decision 2021/002/R** [5], an update of the AMC and GM of EBT to allow authorities to approve the Baseline EBT, establishing a single philosophy of recurrent training within an airline.

Nowadays, there is still a lot of work to be done between EASA, National Aviation Authorities (NAAs) and industry to enable the aviation sector to take advantage of the benefits of EBT. In this regard, **further work is foreseen**, such as the **expansion of EBT to other types of aircraft** and the implementation of Enhanced EBT programmes.

2.1.1 The CBTA Concept

The goal of competency-based training and assessment is to provide focused training for a competent workforce in order to enhance aviation safety. While EBT currently only applies to pilot recurrent training, CBTA applies to the full spectrum of flight crew training (e.g., multi-crew pilot licence, type rating, remote pilot licence), as well as to other roles' trainings such as flight operations officers, flight dispatchers, aircraft maintenance personnel and air traffic management personnel. The main components for implementing a Competency-Based Training and Assessment (CBTA) Programme are shown in Figure 2-1 and explained below:

Figure 2-1 Competency-Based Training and Assessment (CBTA) key elements [6]



1. **A training specification** that describes the purpose of training, the associated task list and the requirements that must be fulfilled when designing the training. It is developed based on a training needs analysis and serves as a basis for the development of the adapted competency framework and the training and assessment plans.
2. **An adapted competency framework**, which should be based on the ones provided by ICAO for each type of CBTA programme and that depends on the training specification, containing competencies with their associated description and a set of behavioural observables related to each of the competencies. In addition, the final competency standard and the conditions of the demonstration of competency are also part of the adapted competency framework. Operators shall use this adapted competency framework to develop the specific training programme and to assess trainees against the defined competencies. The reference competency framework for each type of training or role is provided in ICAO Doc 9868 “Procedures for Air Navigation Services: Training” [6].
3. **An assessment plan** outlining the steps and resources for collecting reliable and solid evidence at different training phases. This assessment plan is intended to detail how each competence is going to be determined when evaluating the trainees. The assessment takes place during instruction and evaluation and can be either formative, which allows trainees to progressively develop competences and identify training needs, or summative, which allows the instructor to collect evidence of the competencies and performance criteria to be demonstrated. Although in summative assessments the decision is "competent" or "not competent", this can be further developed in a more sophisticated grading system. The assessment plan should also define when the assessments are conducted, and which tools are used to gather relevant data.
4. **A training plan** determining the composition and structure of the programme and describing the training required to develop the defined competencies, containing a syllabus that includes knowledge, skills, and attitudes (KSA), milestones, lesson plans and schedules. Thus, it allows the development and delivery of the training programme.
5. **Training and assessment materials and resources** derived from the adapted competency framework and the defined evaluation and training plans, which are necessary to implement these plans. Assessment material could include training notes, exercise briefings, practical exercises, and case studies, among others.

In terms of instructors, and as happens in the case of EBT, operators should provide training and standardisation to the instructors in charge of the training and assessment of the trainees, ensuring that sufficient reliable data is collected and that there is homogenisation in the task of providing a grade.

An Instructional System Design (ISD) methodology shall be applied in the design of competency-based training and assessment programmes, which can serve as a basis to derive the main components of CBTA. As explained in the ICAO Doc 9868 "Procedures for Air Navigation Services: Training" [6] the analysis, design, develop, implement and evaluate (ADDIE) framework is a methodology generic to all ISD models, and it is used in the establishment of a CBTA programme. In the case of a competency-based training and assessment programme, the workflows related to the key components explained above are shown in Figure 2-2.

Figure 2-2 Analyse Design Develop Implement and Evaluate (ADDIE) methodology's workflows for CBTA [6]

Workflow 1	Workflow 2	Workflow 3	Workflow 4	Workflow 5
Analyse	**Design**	**Develop**	**Implement**	**Evaluate**
Training need	Local competency-based training and assessment	Training and assessment materials	Conduct the course in accordance with the training and assessment plans	The course including the training and assessments plans

The first two workflows establish the previously mentioned training specification (1), adapted competency model (2), assessment plan (3) and training plan (4) from Figure 2-1. The third workflow then focuses on the development of the materials based on these elements.

The programme should be conducted following the defined training and assessment plans, monitoring trainees' progress while providing them feedback to enhance performance and remediation should be provided when it is observed that, based on identified needs, a competence can be improved.

Finally, CBTA programmes should include a continuous monitoring and evaluation of the programme. In order to determine and measure the training system performance, the effectiveness of the program in developing trainees' competencies, as well as to introduce improvements into CBTA programmes, a feedback process should be performed, and reliable data should be continuously collected and analysed during the programme. This feedback process should also serve to identify trends and training needs, allowing to address them with corrective actions such as additional training or programme adjustments, and to contribute to the standardisation of the instructors.

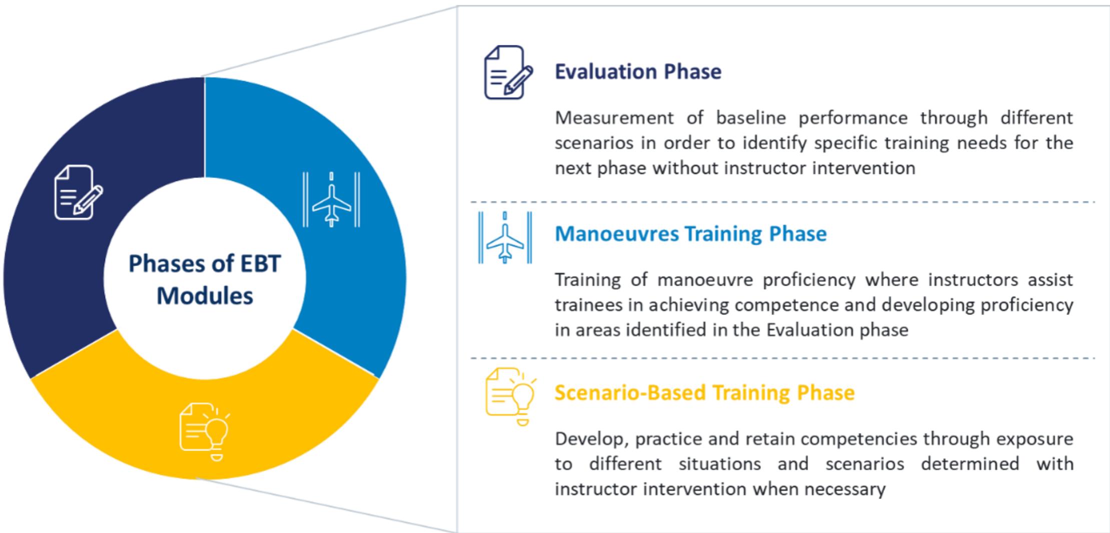
In the context of this case study, the EBT, which is a CBTA-based programme currently applied to recurrent flight crew training, is explored in detail in the next section 2.1.2. The aim of this study is to provide insight and guidelines that encourage stakeholders to integrate digital capabilities that facilitate the implementation of such programmes, also allowing for continuous improvement and monitoring of programme performance. It should be considered that not all operators will be able to implement EBT programmes due to the high resources required for its implementation. In the case of smaller operators with less experience and resources, the adoption of digital capabilities that facilitate the establishment of competency-based training and assessment programmes may be a more realistic option and should be encouraged. The CBTA will have a significant impact on the industry, as it can be applied to all licence types and is available to all operators, who should be supported to implement this kind of programmes. In addition, the industry is moving towards extending the CBTA to all types of roles and positions.

2.1.2 The EBT Programme

Although research on the EBT concept and the development of guidelines for its implementation has been carried out by different international organisations, agencies, and representative bodies (e.g., ICAO, IATA, IFALPA, EASA, etc.), all developments have always been aligned with the aim of a common implementation of EBT. In this regard, the definition of an EBT programme is standardised across all the above-mentioned entities and is defined as a programme aimed to provide more effective and efficient training to pilots through the **identification of core competencies required to operate safely, effectively, and efficiently** based on evidence from both training and operational data.

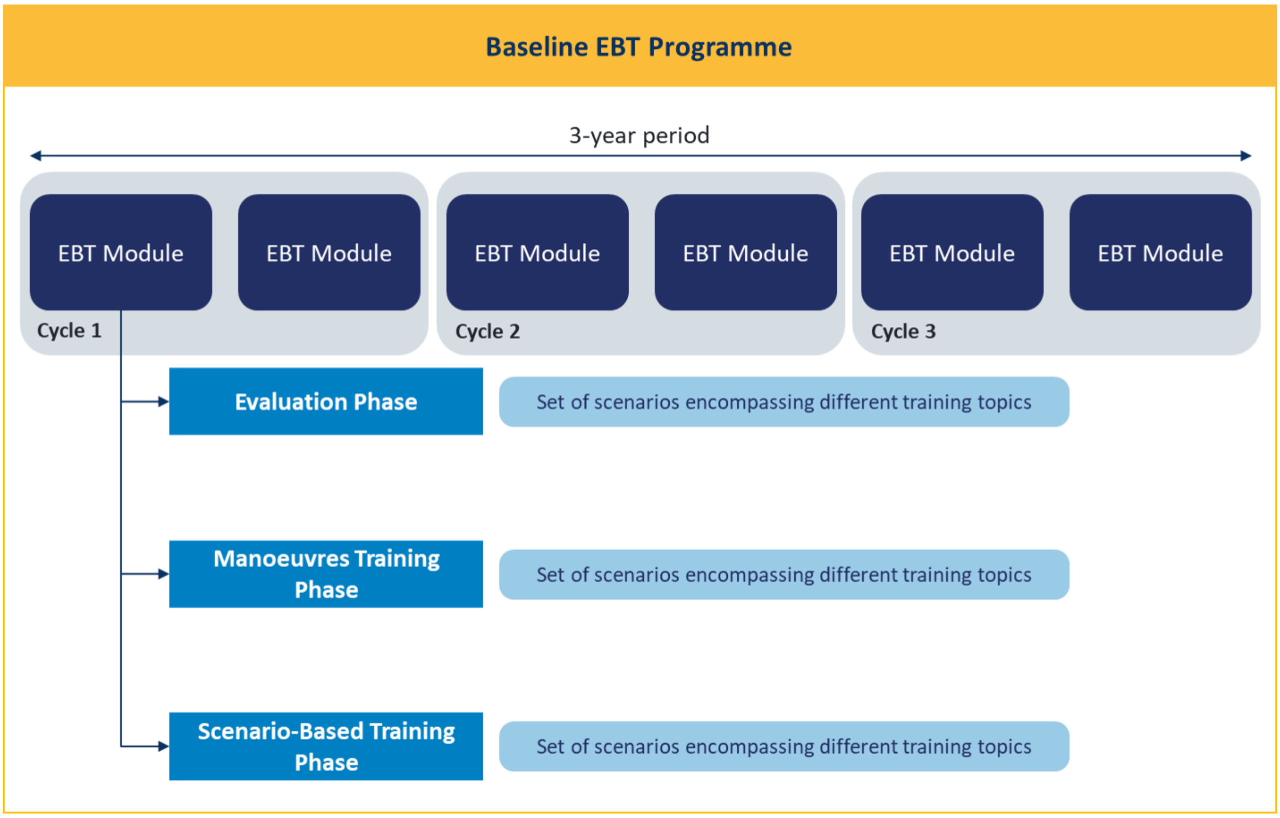
By default, an **EBT programme has a total duration of three (3) years**, during which **all identified competencies should be assessed over a minimum of six (6) separate EBT modules**, defined as the combination of EBT sessions in a qualified Flight Simulator Training Device (FSTD). Each EBT Module should normally contain three (3) different phases: the evaluation, manoeuvres training and scenario-based training phases, as in Figure 2-3.

Figure 2-3 Phases of an EBT Module



Each phase of an EBT module should be divided into different **EBT scenarios** that encompass different training topics. The illustrative organisation of the entire EBT programme is illustrated in Figure 2-4.

➡ **Figure 2-4** Illustrative distribution of modules, sessions, and scenarios throughout an EBT programme



The successful implementation of an EBT programme relies on the identification and assessment of different competencies, as well as their training topics and specific scenarios. To do so, operators should perform a **comprehensive analysis of all available data sources** (e.g., FSTD data, training results, operational data, etc.) in order to obtain detailed insights into the threats and errors encountered in their flight operations and be able to improve the training activity of flight crew and thus, the operational safety.

As can be inferred, **data is at the very heart of the effectiveness of EBT programmes**, as they rely on the continuous and iterative identification of necessary training needs through data analysis. The effective implementation of EBT involves the continuous analysis of large datasets, some of them potentially sensitive from an organizational point of view and thus, requiring the application of a data governance framework. In this sense, **digital solutions can support multiple phases of an EBT programme**, from the adoption phase to the monitoring phase, **facilitating activities to involved stakeholders**, namely regulators, authorities, and operators, which also includes pilots, instructors and examiners.

Therefore, it is important to reflect on how the adoption of data-driven solutions can affect the implementation of evidence-based training programmes, as well as facilitating their adoption, but without neglecting the need to establish standards that ensure the rigorous treatment of data, guaranteeing its quality and proper governance. In this sense, it is equally important to understand how regulation can and should adapt to these future digital challenges, promoting their adoption but serving as a guarantee of the aforementioned precepts.

2.2 Overview of regulatory framework

Before the definition of the case study approach and development, it is crucial to understand the context of Evidence-Based Training through the revision and understanding of the regulatory framework. In that regard, a review of the related regulation and documentation has been carried out, identifying in which areas or phases of an EBT programme digital solutions could potentially fit in.

Table 2-1 presents the main regulations and guidance material related to the definition and implementation of EBT and CBTA, which have been thoroughly reviewed in order to understand the full context of the new regulatory framework and to identify new requirements and challenges for operators and authorities. Additionally, other relevant documentation such as webinars conducted by EASA have been considered.

Table 2-1 Corpus reviewed for CS3

Case Study 3: Flight training data for EBT/CBTA			
Title	**Published by**	**Year**	**Reference**
Regulation and guidance			
ED Decision 2015/027/R	EASA	2015	[3]
Commission Regulation (EU) 2020/2036	OJEU	2020	[7]
Commission Regulation (EU) 2020/2193	OJEU	2020	[8]
ToR RMT.0194	EASA	2020	[9]
ED Decision 2021/002/R	EASA	2021	[5]
RMT.0599 Oversight guidance for the transition to Mixed EBT Implementation	EASA	2022	[10]
RMT.0599 Oversight guidance for the transition to EBT Implementation (Baseline)	EASA	2022	[11]
RMT.0599 Draft EBT Manual	EASA	2022	[12]
Easy Access Rules for Aircrew – Commission Regulation (EU) 1178/2011	EASA	2022	[13]
Easy Access Rules for Air Operations – Commission Regulation (EU) No 965/2012	EASA	2022	[14]
Other material			
Evidence-Based Training Implementation Guide - First Edition	IATA	2013	[15]
Doc 9995 Manual of Evidence-Based Training - First Edition	ICAO	2013	[1]
Data Report for Evidence-Based Training - First Edition	IATA	2014	[2]
Doc 9868 Procedures for Air Navigation Services: Training - Third Edition	ICAO	2020	[6]
Competency Assessment and Evaluation for Pilots, Instructors and Evaluators: Guidance Material	IATA	2021	[16]

Case Study 3: Flight training data for EBT/CBTA			
Title	**Published by**	**Year**	**Reference**
Instructor and Evaluator Training – Second Edition	IATA	2021	[17]
Competency-Based Training and Assessment (CBTA) Expansion within the Aviation System	IATA	2021	[18]
Webinars			
1st Webinar on Evidence Based Training	EASA	2021	[19]
2nd Webinar on Evidence Based Training	EASA	2021	[20]
3rd Webinar on Evidence Based Training	EASA	2021	[21]
4th Webinar on Evidence Based Training	EASA	2021	[22]

2.2.1 Regulatory framework for EBT/CBTA

The effective and recurrent training of flight crew is key to increase operational safety in commercial aviation. In recent years, international efforts have been made to introduce all necessary changes in the flight crew training programmes and new practices have been implemented across the whole aviation community. Specifically, the introduction of EBT/CBTA concepts has been one of the most important implementations.

Although there is limited regulation on CBTA at European level, guidance on the components and elements to be considered by operators seeking to implement CBTA programmes can be found in ICAO Doc 9868 “Procedures for Air Navigation Services: Training” [6] IATA “Competency Assessment and Evaluation for Pilots, Instructors and Evaluators: Guidance Material” [16], “Instructor and Evaluator Training” [17] and “Competency-Based Training and Assessment (CBTA) Expansion within the Aviation System” [18] EASA is working on incorporating CBTA for other licenses by means of RMT.0194 [23] Since the topic of CBTA is much wider than EBT, which currently covers recurrent pilot training, this case study will focus mainly on EBT given its higher maturity in regulatory The results and conclusions on EBT will be applicable to CBTA in a wider scope, as EBT is a CBTA programme.

According to IATA, EBT is the whole **training and assessment process that focuses on improving and evaluating a trainee's overall performance across a variety of competencies rather than specific tasks or manoeuvres**. In this regard, the aim of an EBT training programme is to identify and assess the competencies required to operate safely (competency-based) whilst addressing the most relevant threats and errors according to evidence collected in operational and training data (evidence-based).

After the first publications made by ICAO and IATA regarding EBT methodologies, **RMT.0696 was established by EASA with the objective to facilitate implementation of EBT within the existing European regulatory framework** by producing guidance material and by ensuring a proper alignment with ICAO’s document. This task force, composed by NAAs, CAT operators, manufacturers, and other industry stakeholders, aimed to provide a practical guide to move from repetitive training towards recurrent training of flight crew with the final objective to increase operational safety. As a result, **the first regulatory change was made in 2015, when EASA published the ED Decision 2015/027/R** [3] **for the implementation of Mixed EBT**, a first approach to the implementation of EBT by allowing operators to progressively incorporate EBT into their processes by dedicating only some portion of the recurrent assessment and training to the application of EBT. Thus, this first regulation allowed both operators and authorities to start gaining more experience in this field. The publication of **Regulation (EU) 2020/2036** [7] and **Regulation (EU) 2020/2193** [8] in December 2020 and also **ED Decision 2021/002/R** [5] on March 2021, was a second step in that strategy that has brought the reality of EBT a step closer by addressing the difficulties previously encountered in achieving full EBT deployment in the European regulatory context. These new regulations provided new acceptable means of compliance (AMC) and guidance material (GM) to facilitate the implementation of the new training requirements that are intended to improve pilot competencies.

The current EASA regulatory framework encompasses different training programmes for operators to manage their EBT training processes, namely the Mixed and Baseline EBT. Operators aiming to implement an EBT programme as part of their internal training processes should follow EASA's roadmap, which suggests a **progressive implementation of EBT programmes through two different phases**: the Mixed EBT and the Baseline EBT.

There is a step prior to Mixed EBT called "Assessment according to the principles of EBT" that is not covered by the regulations, but it is the initial step in determining the status of crews in relation to the competencies to be used in the operational environment. It is not usually considered a formal stage of EBT implementation, but operators are also expected to adopt competencies, a rating system and instructor trainings and thus, are expected to follow the same process as in the Mixed EBT phase. These are also key elements of a CBTA programme and are not necessarily expected to progress to an EBT programme. In the case that the operator decides to follow this course of action, this phase may last one or two years, and the traditional training and verification requirements should still be met. However, operators should start assessing the competences in simulator sessions and providing instructor training in order to prepare for the Mixed EBT implementation and approval.

The acceptance of a Mixed EBT programme implies the **dedication of part of the periodic evaluation and training to the implementation of EBT**. The development of a Mixed EBT means partially implementing EBT, while continuing to comply with the traditional requirements (e.g., maintaining Operator Proficiency Check and License Proficiency Check). Thus, the implementation of Mixed EBT allows operators to increasingly gain experience in the EBT concept while maintaining the traditional regulatory structure. In this regard, **operators aiming to implement an EBT programme shall start with a Mixed EBT**, as it allows operators to progressively implement the programme without a high initial effort and also allows them to gain the minimum three (3) years of experience required to extend their training programme to a Baseline EBT, although for most operators it will take longer. Once operators have established and maintained a Mixed EBT during this amount of time, Baseline EBT is the next stage in the implementation process. The detailed implementation process of an EBT programme is defined in the following subsection.

2.2.2 Guidance for the transition to an EBT programme

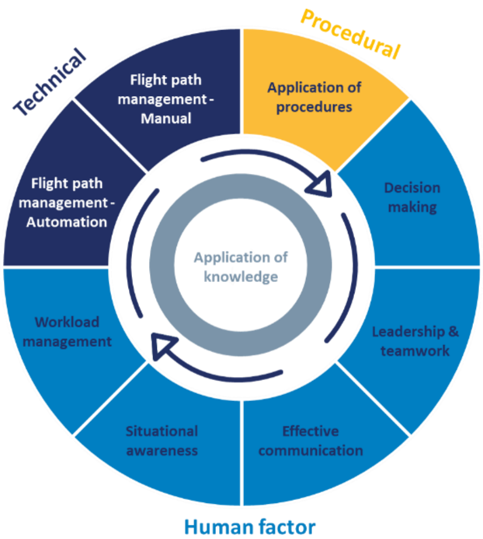
Once the regulatory framework has been reviewed, the implications of the new regulations for the operator in terms of digital capabilities and data integration should be analysed. To identify these new implications, the EBT transition process and the organisational changes involved should be analysed. The aim of this section is to present the general steps to be followed by operators in order to implement an EBT programme and thus, to ease the identification of the needs arising from the new regulation.

According to the project guidance published by EASA, the first step to obtain an EBT approval is to **provide an implementation plan to NAA** that evaluates all requirements and includes milestones and timeframes, as well as to develop a **risk assessment** in accordance with the safety case policy. Once reviewed and approved by the competent authority, operators should continue with the definition of the EBT system per se. According to EASA's webinars on EBT implementation [19], [20], [1], [22], **the operator's EBT system can be divided into three (3) different building blocks**, namely the EBT competency framework, the operator's specific programme and the EBT instructors, described below.

Building Block #1: Competency framework

As defined in [10] EBT is the training and assessment based on operational data and is characterised by developing and assessing the overall capability of a pilot across a range of competencies. Thus, the first step is the **definition and development of the core competencies** required by flight crew members for the safe, effective, and efficient operation of the aircraft. The complete framework of competencies should include the list of competencies to be assessed, as well as their description and related observable behaviours (OB), from which competencies are rated. Operators experienced in EBT programmes could try to adapt a customised competency framework to be approved by the competent authorities. However, a total of **eight (8) core competencies have been identified by ICAO, which operators are encouraged to use as a baseline**. Additionally, IATA and EASA defined a ninth competency, the application of knowledge, which is transversal to all other core competencies. These core competencies can be divided into technical, procedural and human-related competencies, as illustrated in Figure 2-5.

➨ **Figure 2-5** CBTA pilot competencies as EBT Programme core competencies



Each competency may be rated on a scale according to the predefined OBs. Thus, once the set of competencies and OBs are reviewed by the NAA, operators should **develop an assessment and grading system**, which should be reviewed and approved by NAAs. This system should include a rating scale and the minimum acceptable performance in order that any competency observed below the minimum acceptable performance can be addressed through remedial training. Using this rating system when assessing competencies, the training needs of each pilot can be determined and **additional and/or tailored training can be defined for each pilot**, as required by EASA regulations.

Building Block #2: Operator's programme

The operator should **define the EBT programme per se**, which should correspond to the size of the operator and to the nature and complexity of its activities. The EBT programme should:

- Consider the differences between aircraft of different generations, as this generates specific needs for each training;
- Ensure that each pilot receives assessment and training in the management of aircraft system malfunctions (i.e., failures of aircraft systems and associated procedures), taking into account that only those malfunctions that place a significant demand on a proficient crew should be trained under the EBT programme, and in the conduct of approach types and methods relevant to performed operations;
- Include contingency procedures for unforeseen circumstances that could affect the delivery of the EBT modules;
- Include a **feedback process in order to measure and evaluate the EBT system performance through data obtained in the EBT programme** (e.g., grading of the pilots, feedback from instructors and pilots, deficiencies found in competencies, etc.);

- Include procedures governing the protection of EBT data; and
- Include a process of customisation of the training programme based on evidence gathered on data in order to select the example scenario elements within a training topic and to contextualise the example scenario elements based on the operator's operational data (e.g., SMS and FDM programme) and training data. This customisation should be based on both internal and external data collected at three (3) different levels:
    - Individual evidence based on training data (e.g., grading metrics and training reports), analysed either for an individual pilot or a group of pilots;
    - Operator-specific evidence gathered through SMS; and
    - Evidence gathered from external sources (e.g., safety plans from authorities).

Building Block #3: Instructors

On this block, operators should **define and implement an instructor training programme** to give recurrent guidance for the assessment and training of personnel involved in the conduct of EBT. This training programme should include an initial EBT instructor training course and an EBT assessment of competencies during a practical training session (e.g., in a FSTD session). Additionally, the programme should include an **Instructor Concordance Assurance Programme (ICAP)** to reinforce the concordance between instructors (e.g., in the use of the grading system). The ICAP should include, at least:

- A grading data analysis to identify potential elements of the EBT programme that are not working as expected (e.g., instructors not grading properly, competency found difficult to grade, etc.); and
- Grading guidance to help the instructor in the duty of grading.

2.2.3 Applicable requirements for Mixed & Baseline EBT Programmes

The process described in the previous section constitutes the general process for EBT implementation from an operator perspective. However, to facilitate a progressive and sequential implementation, **regulation does not require that all requirements are met for the Mixed EBT**. Therefore, not all steps described above apply to both Mixed and Baseline EBT programmes and a distinction is done in Table 2-2.

Table 2-2 Requirements for the implementation of Mixed EBT and Baseline EBT programme

Mixed and Baseline EBT requirements		
Requirement	**Mixed EBT**	**Baseline EBT**
Building Block 1: Competency framework		
Definition of a competency framework	Required	Required
Definition and utilisation of a grading system	Required	Required
Definition of additional and tailored training based on grading system	Required	Required
Building Block 2: Operator's EBT Programme		
Definition of EBT modules	Required	Required
Definition of a training programme based on training topics and frequencies	Required	Required
Equivalency of Approaches	Not required	Required
Equivalency of Malfunctions	Not required	Required

Mixed and Baseline EBT requirements		
Requirement	**Mixed EBT**	**Baseline EBT**
Customisation of the EBT programme based on the programme's data	Not required	Required
Scenario contextualisation based on operational data and SMS data (e.g., flight crew reports, FDM data, etc.)	Not required	Required
Building Block 3: Instructors		
Instructor training	Required	Required
Instructor Concordance Assurance Programme (ICAP)	Not required	Required

On the other hand, it is also important to consider that although not mandatory in the Mixed EBT, operators should consider including some of these requirements during the Mixed EBT programme to be able to implement Baseline EBT, as minimum experience in some fields is required.

First, since Mixed EBT is intended to be a transitional phase to allow operators to gain experience in EBT, **operators who wish to be approved for Baseline EBT will be required to demonstrate at least three (3) years of experience in Mixed EBT**. There are some additional elements required in the Baseline EBT that require prior experience during the Mixed EBT. In this regard, operators need to:

- Demonstrate 2 years of an instructor concordance assurance programme;
- Demonstrate 1 year of a valid equivalency of malfunctions;
- Demonstrate 1 year of integration of training data in the customisation of the EBT programme; and
- Demonstrate 1 year of integration of SMS data for the contextualisation of the example scenario elements.

In this regard, when transitioning from a Mixed EBT to a Baseline EBT programme, operators should consider defining a roadmap that allows for the inclusion of all requirements that demand prior experience with enough advance. An illustrative roadmap for the inclusion of these additional elements is presented in Figure 2-6.

Figure 2-6 Illustrative roadmap when transitioning from Mixed EBT to Baseline EBT

Element	Timeline				
	Assessment according to the EBT principles	T0+1	T0+2	T0+3	Baseline EBT
Instructor Concordance Assurance Programme (ICAP)			2 years min. experience		
Equivalency of malfunctions				1 year min. experience	
Training data integration for customisation of the EBT programme				1 year min. experience	
SMS data integration for contextualisation of scenarios				1 year min. experience	

Mixed EBT Approval (T0)

Baseline EBT Approval (min. T0+3)

2.3 Digital capabilities and solutions

The regulatory framework sets the basis of the transition to a complete EBT framework that needs to be defined, developed and managed with a robust data-driven ecosystem in order to extract meaningful evidence from collected data. This proves that digital capabilities have a fundamental role to help operators meeting the requirements of this regulation regarding data collection, analysis, and protection, as well as being a powerful tool that can significantly assist in the implementation and continuous improvement of EBT programmes.

The aim of this section is to provide a broad overview of the state-of-the-art of digital capabilities and solutions that support the application of EBT programmes, focusing on EBT phases and areas where the use of data is paramount, and which have been identified based on the requirements of the regulation. In addition, the analysis of digital capabilities will serve to determine any prospective regulatory development and to identify potential opportunities that need further examination during the development of the project. Research initiatives reviewed as part of this analysis is included in Table 2-3.

Table 2-3 Research identified for CS3

Case Study 3: Flight training data for EBT/CBTA			
Product Name / Paper Title	**Owner / Published by**	**Year**	**Reference**
Papers / Scientific studies			
An incremental clustering method for anomaly detection in flight data	W. Zhao, L. Li, S. Alam & Y. Wang	2021	[24]
Anomaly Detection in Aviation Data using Extreme Learning Machines	V. M. Janakiraman & D. Nielsen	2016	[25]
A data-driven model for safety risk identification from flight data analysis	M. Rey, D. Aloise, F. Soumis & R. Pieugueu	2021	[26]
Hybrid Machine Learning–Statistical Method for Anomaly Detection in Flight Data	S. K. Jasra, G. Valentino, A. Muscat & R. Camilleri	2022	[27]
AI in Pilot Training and Education - Towards a ML Aided Instructor assistant for Flight Simulators	S. Yang, K. Yu, T. Lammers & F. Chen	2021	[28]
Augmenting Flight Training with AI to Efficiently Train Pilots	M. Guevarra, S. Das, C. Wayllace, C. D. Epp, M. E. Taylor & A. Tay	2022	[29]

2.3.1 Data layers supporting EBT programme

Based on the foundations laid by the current regulatory framework, EBT programmes should be periodically adapted and customised based on evidence gathered from data, which is considered the greatest asset of all EBT building blocks. Consequently, operators should conduct an overall data collection and analysis to periodically review the programme to ensure that pilots are developing the defined competencies and that the training needs of the pilots are being met throughout the programme, this being an iterative process. In this regard, it is of vital importance to identify all available data sources that allow the periodic review and customisation of an EBT programme.

EASA states that evidence can be gathered from both the operator's **internal sources** (e.g., data generated during training sessions, operational data, SMS data, etc.) and from **external sources** (e.g., authorities, manufacturers, safety plans, etc.) to assess and customise each EBT building block. At the same time, these **data sources can be classified according to their nature in relation to the EBT system**:

- Data from within the training activity and the EBT programme itself (**internal EBT training data layer**), from which evidence can be extracted and analysed either for an individual pilot or a group of pilots (e.g., grading of the pilots, feedback from instructors and pilots, deficiencies found in competencies, training session data, etc.). These data sources are highly valuable in identifying trends and specific needs on which to base tailored training. For instance, if a competency is identified as being deficient among operators or pilots, subsequent EBT programmes should strengthen this competency. The inner data layer should deal with data privacy by applying data de-identification processes when appropriate.
- Data generated outside the training programme (**non-training data layers**), from which specific evidence can be gathered to perform the contextualisation of the example scenarios and the customisation of the operator's EBT programme. The external data layers can be divided into:
    - **Regulators and other industry wide data:** In addition to internationally available EBT data, data from the wider aerospace industry should be considered to enhance and particularise EBT programmes. Operators should consider data from regulators (e.g., Mandatory Occurrence Reporting, Annual Safety Review trends, etc.) and other stakeholders (e.g., Original Equipment Manufacturers) when defining or customising the programme.
    - **Airline operational data (internal operator data):** Operational data from the airline itself is key to customise the EBT programme, as it reflects the actual operational environment of operators. In that regard, the Safety Management System (SMS), the Flight Data Monitoring (FDM) programme or its own Safety Performance Indicators (SPIs) are key data sources to be employed.

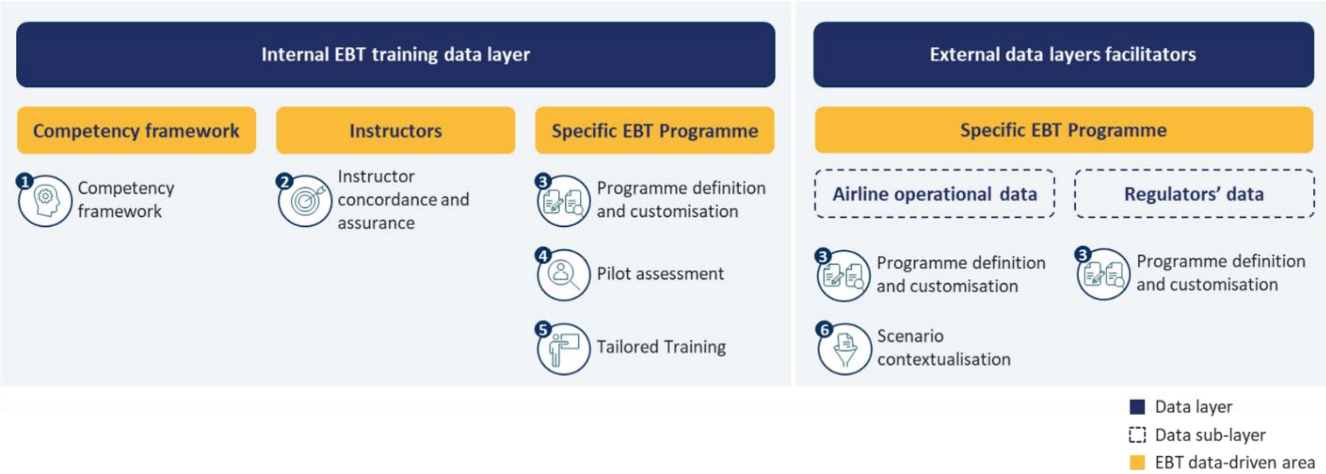
Operators aiming to take full advantage of data coming from the internal training loop should define robust and well-calibrated training metrics. However, in some EBT blocks, **data collected from the training activity itself should be placed in the context of operational data**, as it allows to provide context to training data and to detect specific training needs based on actual operations. Therefore, the use of both separate and fusion data sources is a key asset for the proper customisation of EBT programmes and thus, for regulatory compliance.

2.3.2 Mapping between EBT data-driven areas and data layers

Data mapping is crucial to the success of most data processes, as it determines the quality of the extracted insights. Therefore, once the different data sources that can benefit the EBT environment have been identified, they are mapped to the specific areas within an EBT programme where they can be useful.

Based on the building blocks defined in Section 2.2.2, areas where it is relevant to incorporate data to ensure the correct functioning of the programme have been identified and classified as presented in Figure 2-7. The use of data in these areas allows to gather evidence and to customise the programme based on extracted insights.

Figure 2-7 Illustrative mapping between EBT data-driven areas and data layers



The sub-sections below define and expand the areas or capabilities of the EBT programme where data can play a significant role in facilitating the implementation of such programmes by operators, as well as helping to meet regulatory requirements. Additionally, based on the two (2) aforementioned data layers, each identified area is mapped with its corresponding data source.

2.3.2.1 Internal EBT training data layer

The internal EBT training data layer encompasses the areas or capabilities that can benefit from the implementation of digital capabilities based on data generated by the operator's own EBT programme. The identified areas fall within the three (3) building blocks of EBT identified in Section 2.2.2, namely the competency framework, instructor concordance and assurance and the operator's specific EBT programme.

Area #1: Competency framework

The definition and development of a competency framework is essential for the implementation of EBT, as pilots will be assessed based on their performance in these competencies through different training topics and scenarios. In addition, the use of an objective grading system is key to assign a score to each competency and to define additional or tailored training when performance is below the minimum acceptable performance. Thus, the goal of this area is to adapt the competency framework to the particular operating environment while maximising the development of the defined competencies and facilitating the collection and analysis of training data.

The digital capabilities to be considered under this area facilitate the definition of the competency framework through the collection and analysis of data generated during the training itself. The in-depth analysis of this data allows operators to gain relevant insights regarding pilots' performance in specific areas and therefore to identify new competencies to be trained, new training topics and tailored training for specific pilots. Thus, operators should consider implementing digital capabilities that allow collecting an adequate set of training data and developing the necessary methods to analyse the data and to produce a criticality ranking of competences and training topics. In addition, digital solutions facilitate the aggregation of all data related to the grading system, which allows to have an overview of the results and to draw conclusions more efficiently.

Area #2: Instructor concordance and assurance

In order to ensure the integrity of each EBT programme, regulations place a significant focus on the necessity of overseeing and ensuring instructors' concordance, defined as the consistency of scores between different EBT instructors that is measured through the homogeneity, agreement and alignment of the instructors' ratings. As stated in the regulation, operators should establish an Instructor Concordance Assurance Programme (ICAP) in order to identify areas of weak concordance and to drive improvement in the quality and validity of the grading system. Thus, operators should define and implement procedures to carry out ICAP-specific data analysis to verify the concordance of instructors.

In that regard, digital capabilities are a great asset in this area of the EBT programme, as operators can highly benefit from a robust set of analytical tools to:

- Define and employ suitable metrics and methodologies to evaluate concordance through statistical methods, gauging both individual and group metrics;
- Perform corresponding analysis of consolidated grading data to ascertain whether all the EBT programme's components are working effectively; and
- Identify the root cause and potential actions for enhancing the programme and the instructors' standardisation (e.g., provide additional concordance training in specific cases where sufficient standardisation is not observed on the gathered data) through corrective training derived from the identified needs.

Digital solutions that allow to statistically analyse and to aggregate data could be useful to operators to have a big picture of instructors' concordance and to implement, if necessary, measures to ensure standardisation. Concretely, operators could benefit from solutions that display heat maps and correlation analysis to perform individual assessments and from group statistics, such as variance assessments. This way, operators are able to assess the extent to which an instructor aligns with predefined standards, as well as assess the instructor's ability to evaluate their improvement or deterioration during the EBT programme. It is also worth noting that processes of anonymisation of information should be considered so that the whole process ensures just culture and data protection.

Area #3: Programme definition and customisation

The operator's EBT programme should be continually reviewed and adapted based on evidence extracted from data in order to ensure that the training programme is always adapted to the specific needs of each trainee. Although this definition and customisation should be based on evidence gathered both from internal and external data layers, this section focuses on evidence gathered from the training data itself. The customisation of programmes by means of external data layers is further developed in Section 2.3.2.2.

The customisation through data gathered within the EBT programme itself should consider different data silos such as pilot evaluation ratings, grading metrics, training reports and training sessions' data, among others. In addition, a continuous process of gathering and analysing training data from the EBT programme, known as feedback process, should be conducted and its outputs should be used to evaluate the performance of the EBT system. Thus, operators should carry out a transversal analysis of all data collected from the different areas and phases of the programme to check the programme's optimal functioning and to identify all possible improvements to be applied in terms of the programme structure and contents.

In this regard, operators could benefit from digital solutions that allow to integrate all these data sources while proposing programmes with modules or scenarios tailored to the needs of the operator and pilots, considering aircraft generations' particularities, system malfunctions clustering and approach types clustering. This kind of digital capabilities would be highly beneficial in terms of regulatory compliance, as well as improving the overall performance of EBT programmes and adapting them to the identified needs.

Area #4: Pilot assessment

As required by EASA's regulations, every competency should be assessed during the different phases of each EBT module by means of a predefined grading system that should include a rating scale and the minimum acceptable performance. Any competency observed below the minimum acceptable performance should be addressed through the definition of additional training for each pilot.

Given the complexity and relevance of pilot assessment, the integration of digital capabilities to assist instructors in conducting pilot assessments during the phases of the different modules of the EBT programme while guarantying the reliability of instructors, should be considered. For this purpose, it is possible to implement tools that facilitate the task of assigning a grade to the different defined competencies by means of customised forms, that support the recognition of the appearance and correct application of competencies or that allow to consolidate the data obtained during the sessions, thus providing a global and data-driven vision of the pilot's performance and allowing the identification of training needs while reducing the workload of instructors. In this case, it must be noted that the EBT grading system is based on assessing the overall pilot performance over the whole EBT module, rather than measuring single events. However, although the use of tools to assist instructors and evaluators are highly beneficial and should be encouraged, the instructors' judgement should still be relied on when assigning the grade.

Another important point in this regard is that processes of de-identification of pilot information should be considered when consolidating data from several pilots, with the aim that these tools contribute to improving the development of the defined competencies by following 'Just Culture' policies.

Area #5: Tailored training

The regulation differentiates between the customisation of syllabi at operator's level and the customisation of training at individual level by introducing the term 'tailored'. The previous Area #3 encompasses the contextualisation of the operator's EBT syllabi, meaning the adaptation of the competency, training topics and grading system that must be performed at operator level. The objective of tailored training (Area #5) is to ensure that each pilot develops and enhances those competencies that have been highlighted in previous EBT phases and that are necessary to operate the aircraft safely, efficiently and effectively, and this means that operators must provide specific training for their pilots based on the needs identified during training sessions by instructors.

This is a key area in order to ensure that each pilot acquires the right knowledge and proficiency in the defined competencies, correcting all behaviour that can be enhanced. Given the importance of this area in the EBT environment, and given that data analysis should be done for each pilot separately, operators can benefit from digital solutions that facilitate these tasks by collecting data and by finding trends and insights that allow to identify potential improvements and further trainings for flight crews. Operators should consider implementing digital capabilities that allow the identification and definition of training topics and scenarios fully adapted to pilots based on their particular needs.

2.3.2.2 External data layers facilitators

In the case of this group, the data used for the design and customisation of the EBT programme, as well as example scenario contextualisation, comes from sources external to the EBT programme itself. These sources are supplied by two different external data layers: the operators themselves and the regulators.

Area #3: EBT programme definition and customisation

The definition and customisation of the operator's EBT programme could use external data layers, as they are important sources of information on the current state of operations within the operator and the industry.

From the operator, key data sources to be considered include all SMS-related data and reports, internal LOSA audits and other operational data, like SPIs and trends from the FDM programme. These data sources serve the EBT programme by the safety-focused context they provide in terms of identifying and quantifying operational risks. The structure and focus of the syllabus can thus be adapted for pilots to improve those competences that internal operational data shows to be more in need, as it could be concerning risk scenarios. Additionally, an external feedback process can be established to evaluate the overall effectiveness of the EBT programme through the usage of FDM programme data. The analysis of aggregated flight data pre- and post-training can serve as an additional tool to evaluate the current EBT programme and refine those practices, methodologies or parts of the programme that require it to ensure the actual benefit in terms of flight safety is observable in-flight data. Additionally, the usage of Artificial Intelligence (AI) algorithms for anomaly detection over flight data will enable, in the future, the detection of safety risks for which there are no obvious precursors and incorporating them into the EBT programme, helping pilot's build resilience to the unexpected.

From regulators, industry-wide information on safety key risk areas, which can be translated into training priorities, are available in EASA's Annual Safety Reports, built upon the European Central Repository (ECR) of safety reports. The usage of industry-wide information helps the operator in evaluating the relative importance of their safety risks to those of other operators and thus aid in focusing the EBT programme definition.

In the opposite direction, regulators (and other operators) might also be interested in collecting data on the EBT programme implemented by the operator. Regulators could benefit from collecting data to better understand how these programmes are being implemented and establish future regulations that serve all stakeholders and ensure the highest levels of safety. Other operators, on the other hand, might be interested to benchmark their own implementations. This may include the comparison of scenarios, grading systems, and other methodologies. Nonetheless, despite the clear benefits of data exchange programmes for the overall EBT programme improvement, a thorough assessment must be performed to build robust data sharing policies and governance which consider all required protection, just culture and security layers to handle such sensitive data as the one generated under the EBT programme. Within the context of EASA Member States, the Data4Safety programme is already collecting flight data from multiple European operators and could serve as a platform for EBT programme data collection (see Section 4.3.1 for further detail).

Overall, operators could benefit from digital solutions that seamlessly integrate all these data sources with those from the Internal EBT training data layer.

Area #6: Scenario contextualisation

The programme must demonstrate that the example scenarios are appropriately contextualised based on the operator's actual operation and feedback from the SMS. The objective is to ensure that the scenarios are representative of line operations, and so are the key competencies assessed and developed in the EBT programme, ultimately allowing crews to participate in training sessions that are closer to what they will encounter on a day-to-day basis on that particular operator.

To that end, the operator shall use information sourced from operational flight plan data, SMS data, flight data or pilot reports. The regulation defines that in order to progress to the Baseline EBT, 1 year of experience in the integration of SMS data must be demonstrated for the contextualisation of the example scenarios. The authority may require the operator to demonstrate how such scenarios are selected and contextualised, as well as to demonstrate that it uses a system to design the EBT programme. Therefore, the implementation of digital solutions can largely contribute to regulatory compliance and improved training output.

Data is to be used in the contextualization of scenarios at different customization levels: customizing per type rating level/aircraft generation level, or per aircraft type/crew role (i.e., captain or first officer). The aforementioned data sources will be used as a support tool for the definition of scenarios. They can be used by establishing the type of operation which is being performed (e.g. approach to a particular airport, from flight plan data), the environment under which the operation takes place (e.g. crosswind of a particular strength at a particular altitude, from flight/SMS data, pilot reports or other meteorological external provider's data) and what other unexpected events may occur (e.g. cabin smoke, from SMS data and pilot reports).

The use of flight data for training is challenging, given the de-identification requirements imposed by regulation (see Sections 4.1.1 and 4.2.1 for further detail). It is not possible to contextualise scenarios for a particular pilot with data that can be traced back to that or any other pilot. To overcome this limitation, no individual data is to be used tailored to a pilot, but instead the aggregation of data from multiple operations. Additionally, flight data sourcing is not limited to the internal data generated by the operator. Industry-wide FDM programmes can serve as a repository of de-identified flight data for operators, particularly useful when contextualising scenarios for which the operator has no past data (e.g., training for an airport with a complex approach where the airline has not previously operated).

In this regard, operators could benefit from digital solutions that allow to integrate all these data sources while automating the contextualization for a given scenario by informing on actual past operations which are similar to the scenario defined. This kind of digital capabilities would be highly beneficial in terms of improving the overall performance of EBT programmes by reducing the workload on the definition of new scenarios.

2.3.3 Digital solutions functionalities

Based on all areas that have been defined by considering the regulatory requirements and the collection and usage of data during the development and conduct of EBT programmes, both the digital products currently on the market and the research that has been carried out in the field of EBT have been identified and reviewed.

As can be inferred from the requirements of the regulation, digital solutions can play a crucial role in the implementation of EBT programmes, as they support regulatory compliance while also providing operators with very useful tools for the deployment, conduction, and customisation of the programmes. The set of solutions identified and analysed, which aim to facilitate the implementation and continuous improvement of EBT programmes, have a transversal approach, as they mostly support the majority of areas of an EBT programme where data is collected and analysed while assisting operators, EBT managers, instructors, pilots and examiners.

These different solutions assist in the partial integration of the operational data from the operator and training session data gathered during the phases of the programme, and support the identification of programme improvement areas, suggesting customised training sessions accordingly. Instructors are able to record pilot performance and behaviours during training and to provide insights by means of the competency framework and grading system related data collection and analysis. In addition, the pilot assessment conducted by instructors is supported with tools that assist grading on the different competencies while performing data-driven analysis to provide a detailed overview of the pilots and instructors performance. It is worth noting that many of the solutions studied are compatible with both Mixed and Baseline EBT, which would help smaller or less experienced operators to also start implementing EBT and would allow a smoother transition between both programmes. In terms of the specific functionalities of the identified solutions, the most relevant ones are described in Table 2-4 in relation to the previously defined digital areas and capabilities.

Table 2-4 Digital solutions' specific functionalities

Data-driven area from EBT building blocks	Data layer	Illustrative functionalities based on on-desk research
Area #1: Competency framework	Internal EBT training data layer	• Assisting on the design, development, delivery, and customisation of training programmes for technical and non-technical skills by means of the partial incorporation of operational and training data. This kind of solutions allow to understand trends and support operators with the delivery and assessment of tailored training, as well as with the creation of training matrix tasks in relation to competencies, observable behaviours, desired outcomes, cluster of malfunctions and cluster of approaches, among others.

Data-driven area from EBT building blocks	Data layer	Illustrative functionalities based on on-desk research
Area #3: EBT programme definition and customisation	Internal EBT training data layer External data layers facilitators	• Conduction of performance analysis, definition of KPIs for pilots/instructors/examiners, provision of data visualisations and creation of custom reports and advanced queries based on the gathered data in order to identify trends in training data to better understand which factors drive training performance and identify possible training gaps. In addition, some solutions include AI-powered data-driven competency analytics to improve training effectiveness and efficiency.
Area #2: Instructor concordance and assurance	Internal EBT training data layer	• In-depth analysis of the grading provided by the instructors, observation and record of the instructor findings, classification of notes into objective data and support of the instructor standardisation by means of analytical tools.
Area #4: Pilot assessment	Internal EBT training data layer	• Facilitation of the evaluation of pilots based on the data collected, supporting electronic grading, notes taking and data analytics, promoting the standardisation of the pilot assessments. It is possible to capture required essential data for the programme by means of the design and provision of evaluation and training forms and grading systems designed to provide data entry automation and validation. • In addition, some solutions allow to perform real-time analysis of flight simulator data and reveal strengths and deficiencies, infer core competencies, and provide insights into how each flight manoeuvre is executed. In this way, operators can measure the individual strengths and weaknesses of each pilot and can perform the competency assessment through objective metrics and automatic detection of activity by means of deep neural networks.
Area #5: Tailored training	Internal EBT training data layer	• Monitoring and comparison of pilots to support the decision-making of training managers in terms of defining, assigning and tracking remedial and tailored training (e.g., extra e-learnings, simulations, videos or case studies, etc.) in order to address the weak areas detected through data analytics. Some solutions even include the provision of 3D animations based on recorded flight data which can be used for performance assessment during debriefings, and also allow to replay flight sequences of interest. This allows to select pilot's specific manoeuvres or situations that need further training.
Area #6: Scenario contextualisation	External data layers facilitators	• Provision of built-in existing scenarios and competency mapping recommended by ICAO, also allowing to add new scenarios with identified appropriate competency mapping and incorporating EBT topic and scenario validation. In addition, specific scenarios are recommended to address identified flight crew individual training needs related to certain areas. Some solutions allow to practice a large set of normal, abnormal,

Data-driven area from EBT building blocks	Data layer	Illustrative functionalities based on on-desk research
		and emergency scenarios with a simulated flight deck, cockpit screens and 3D functionalities. • Besides that, multiple scientific and academic studies aim to develop data-driven approaches by means of data analysis methods and machine learning algorithms. The main objective of this research field is to perform accurate analysis of both flight and training data in order to detect potential safety risks, flight and training anomalies and to detect specific operational patterns of interest. Such analyses could be considered for the contextualization of the scenarios based on operational and training data of the operators, as it is possible to detect trends and possible operational risks that should be incorporated into EBT programmes.

2.4 Conclusions

The integration of digital capabilities and solutions is of utmost importance for the definition and continuous improvement of training programmes, as well as in their proper functioning. By shifting the paradigm and approach of training programmes, the aim is to ensure that pilots develop and acquire the multiple competencies required for increased efficiency and safety in the operation of aircraft, which are constantly evolving. Additionally, evidence-based trainings aim to ensure that pilots are prepared to deal with both expected and unforeseen events. Operators should be encouraged and assisted to further implement CBTA and EBT programmes, as the implementation of CBTA and EBT programmes and the use of data related to their definition and continuous improvement bring a number of benefits to the aviation industry, such as:

- Enhanced pilots' skills and learning through an approach oriented to the development and application of defined competencies necessary to deal with expected and unexpected events, which improves pilots' performance and, in consequence, enhances operational safety;
- Establishment of a common training philosophy across operators and regulators, helping it to be extended to other aircraft types and positions, as the market seems to be moving towards the application of EBT for ATCOs, flight dispatchers, etc.;
- Improved exploitation of both operational and training data at all areas of the programmes, enabling continuous improvement of programmes through the identification of training needs derived from the analysis of such data;
- Improved decision-making related to operator training programmes and tailored training for pilots, as a result of data analysis based on the gathered data;
- Reduction of the workload of staff involved in CBTA and EBT programme tasks, leading to a better performance of the programmes; and
- Potential cost savings related to overall improvement of operations' safety and efficiency. Implementation of EBT is expected to bring 0,03% saving of operator's turnover for medium and large operators (>1000 pilots) and 0,02% for small operators (<100 pilots), according to the Cost–benefit analysis performed by IATA [62].

However, certain potential limitations and challenges in the implementation of such EBT programmes must be considered:

- **Need for the identification of the relevant data for EBT and CBTA programmes:** Data is an essential pillar in all areas of an EBT programme, serving to verify the correct performance of the programme and for its definition and customisation. Given that multiple data sources are used for the definition and customisation of EBT programmes and that data is also collected and analysed during the conduct of the programme, it is of utmost importance to determine which data is relevant, which specific parameters should be taken into account for the programmes and under which criteria each parameter is to be considered reliable and significant for each task at hand. Operators might end up gathering a huge amount of data and need to establish procedures to extract relevant insights from it, as well as to perform adequate benchmarking for performance evaluation purposes. As for CBTA, there is a wealth of data that could potentially facilitate the work of building and implementing competency-based programmes, but this data is not structured and the analysis and selection of relevant data is the main limitation. In this regard, a thorough analysis would be needed in order to filter and select the data to be used, thus making it easier for operators with fewer resources to access CBTA programmes.
- **Challenge in the definition of policies for information security and data protection:** Operators must be able to perform analysis of the data collected through different data sources to draw conclusions that can be integrated as improvements to the EBT programmes with the objective of improving the performance of pilots and the development of the defined competencies. This requires the availability of such data and it must be ensured that it is not inappropriately used, which implies that operators should develop a comprehensive data security and governance framework to ensure that EBT data is collected, processed, and stored in a manner that protects the privacy and confidentiality of pilots. According to GM2 ORO.FC.231(c), this framework should include policies and procedures for access control (limiting access to EBT data to authorized personnel), data retention and storage, data de-identification (ensuring that data is appropriately de-identified to protect the privacy of individual pilots) and data integrity. While guidance material provides useful information on the importance of information security and data protection for EBT programs and also recommends following established standards such as ISO 2700x and NIST SP 800-53, it does not provide detailed guidance on how to develop policies and procedures to achieve these goals, even more in a context of needing fusion between flight crew training and other sensitive data sources (e.g., flight crew reports). This lack of specific guidance can pose a challenge for operators who may not have the expertise or resources to develop a comprehensive data security and governance framework from scratch.
- **Challenge at integrating and fusing the different data sources employed for definition and customisation of EBT programmes:** As previously stated, the definition and tailoring of EBT programmes involves the use of multiple sources of data from different origins and with specific particularities, since these programmes are fed both by data collected through the EBT programme itself and by data external to the programme, such as operational data from the operator and data from the regulator. Guidelines or recommendations concerning the methodology for data fusion and integration should be defined and developed, since massive amounts of data are involved, allowing the extraction of insights that help to understand and validate the performance of the programmes as well as to improve them by addressing the identified needs. Such methodology definition, as well as the development of data models, is highly time-consuming and not a simple task for the operator, therefore the implementation of digital capabilities that assist the fusion of data in a structured way should be considered, trying to make the process as standard as possible. With all this available information, it would be possible to perform benchmarking and to draw conclusions that could be applied to the programmes, also evaluating the performance.

- **Challenge of processes & integration of data capabilities:**
  - Beyond data modelling and technical methodologies, the organizational and data governance dimension should not be neglected. A large portion of the data used by operators in the context of EBT programmes resides in the safety department, but data collected through the training programme itself is also used, so operators who intend to use internal and external data layers will need to analyse these data in conjunction, which will require close cooperation between the training and safety departments. In this regard, the taxonomy of training data and the taxonomy of safety data should be aligned, since in some cases it will be necessary to combine such data to satisfy both safety and training interests.
  - The definition of digital capabilities and their integration with processes should be based on knowledge of the business. In this sense, the application of new advanced capabilities such as automation with AI/ML requires a complete deployment process in which different operator profiles contribute, from training to testing. In addition, it is essential to perform the continuous validation of the whole process to make sure that the digital solutions fit the training environment and that obtained results make sense from a business perspective.
- **Challenge of scaling-up the EBT programme through data exchange programmes:** As previously stated, operators can benefit from exchanging data on their EBT programme with other operators and regulators. These include the enabling of benchmarking capabilities on any number of components of the EBT programme, including length, complexity and effectiveness of scenarios, or grading systems and other methodologies. It also includes the definition and contextualization of scenarios based on other operators' flight data, especially valuable when training for scenarios or in the context of airports that for which the operator does not have data. Nonetheless, a thorough assessment must be performed to build robust data sharing policies and governance which consider all required protection, just culture and security layers to handle such sensitive data as the one generated under the EBT programme or outside but which can serve as an external data layer to the programme.

3. Case Study 4: Digital fuel management

3.1 Introduction

According to statistics regarding CO_2 emissions from commercial aviation worldwide published by *Statista [31]* global CO_2 emissions from total passenger and cargo aviation have increased continuously since 2004. Just before the COVID pandemic started, the amount of CO_2 emitted by commercial aviation had increased a 44%, reaching over 900 million metric tons of CO_2. During 2020, the pandemic paralyzed global aviation and thus, emissions were considerably reduced to 495 million metric tons. However, as the recovery began to ramp up through 2022 and beyond, global emissions slightly started to increase again. IATA's latest analyses (published the 6th February 2023) revealed that global air traffic in 2022 (including both domestic and international traffic) was at 68.5%% of pre-pandemic levels. Therefore, it is expected that the CO_2 emissions of air transport reach pre-pandemic levels in the near future.

Since global emissions started to increase, several organisations and agencies started working on the **development of new fuel policies as part of global efforts to reduce the impact of aviation on the environment and boost the efficiency of its operations**. It all started in 2008, when the Joint Aviation Authorities (JAA) asked its Operations Steering Group to extract all relevant fuel material from JAR OPS Part 1 and Part 2 in order to prepare the transition into the new EU-OPS, which was published the same year. Shortly after its publication, IATA improved their policies and aligned them with the new European policies.

Four years later, in 2012, ICAO developed new fuel standards and published two relevant documents: the regulation itself (Amendment 36 to Annex 6) and the manual to end-users (Doc 9976 Flight Planning and Fuel Management). These new standards allowed performance-based variations in order to improve overall operational efficiency and reduce emissions of air operations. This began a gradual transition in the industry's mindset from a prescriptive approach to fuel management to a proactive one based on the performance of operations and the assurance of safety levels.

Finally, in 2015, EASA launched the Rule Making Task RMT.0573 'Fuel procedures and planning' in order to comply with the new ICAO standards, resulting in the introduction of a new and safe European fuel policy with different levels of performance-based variations. The latest regulation, whose application started on 30th October 2022, allows operators to reduce the amount of fuel carried during operations and thus, to reduce CO_2 emissions and environmental impact of flights. In addition, the use case is of extreme interest to operators, enabling a new operational framework under which direct efficiency levers can be introduced that can ultimately enable significant savings for operators.

The new EASA regulatory package introduces the '**fuel/energy schemes'** concept, which encompasses three different frameworks for operators to manage their operations' fuel/energy planning & consumption, ranging from a basic and mandatory one to two advanced and optional schemes that introduce more flexible and performance-based components. By setting up different schemes, EASA wants to introduce a progressive implementation framework to ensure that each airline adopts an appropriate fuel/energy scheme adapted to its current operator control capabilities. In this sense, the framework of progressive schemes also enables incremental benefits through more flexible systems tailored to the performance of operations but, at the same time, requires more advanced monitoring and fuel management capabilities, supported **by a new ecosystem of digital solutions**.

Indeed, the **transition to digital fuel management systems** allows operators to develop a detailed fuel monitoring capability over different time horizons, as well as to introduce potential optimizations in the fuel carried during operations. However, despite the potential optimizations that these solutions can bring and their consequent reduction in environmental impact, this can never occur at the expense of a reduction in safety levels. It is crucial to ensure the aircraft carries enough fuel to ensure the safety of operations in case of unforeseen events, such as delays on approach to the destination airport or landing impossibility due to weather conditions.

As we can begin to understand, the future ecosystem of digital solutions that will support the new mind-set for fuel management can and must go beyond pure fuel management capabilities. Additional capabilities that are progressively being integrated into this ecosystem include the fusion of new external data sources that incorporate operational information (e.g., weather information) or company safety performance (e.g., FDM data, reported occurrences) or predictive capabilities. The use of state-of-the-art digital solutions for fuel planning and management already provide many of these capabilities and can enable the adoption of more optimal schemes that save fuel and reduce environmental impact without compromising safety levels. Beyond this, new lines of research and development of advanced analytics products (e.g., AI-based predictive models), will enable potential avenues for greater and safer adoption of more tailor-made fuel schemes.

3.2 Overview of regulatory framework

Before developing the case study, it is important to conduct a thorough analysis of the regulatory framework for fuel/energy management in order to gain an understanding of it, and more specifically, of the requirements established and guidance elements issued for compliance and adoption. In short, to understand the regulatory framework in order to subsequently be able to assess how new digital capabilities are contributing to it and how future trends may impact its evolution. Documents reviewed include the main regulations in the context of EASA Member States, published Acceptable Means of Compliance (AMC) and Guidance Material (GM), as well as other guidance material from national and international authorities and entities. Additional material has been reviewed to gain more visibility on the practical application of the new fuel/energy regulations, including webinars organised by EASA and documents published by the FAA and aircraft manufacturers.

Table 3-1 Corpus reviewed for CS4

Case Study 4: Digital fuel management			
Title	**Published by**	**Year**	**Reference**
Regulation and guidance			
Commission Regulation (EU) No 965/2012	OJEU	2012	[32]
ICAO SARPs on fuel planning and management (three different amendments to Annex 6)	ICAO	2015-2018	[33]
Doc 9976 Flight Planning and Fuel Management (FPFM) Manual	ICAO	2015	[34]
Opinion 02/2020 Fuel/energy planning and management	EASA	2020	[35]
Commission Implementing Regulation (EU) 2021/1296	OJEU	2021	[36]
AC 150/5230-4C - Aircraft Fuel Storage, Handling, and Dispensing on Airports	FAA	2021	[37]
ED Decision 2022/005/R: Fuel/energy planning and management - fuel schemes	EASA	2022	[38]
EASA Easy Access Rules for Air Operations Annex IV (Part CAT) Subpart B: Operating Procedures	EASA	2022	[14]

Case Study 4: Digital fuel management			
Title	**Published by**	**Year**	**Reference**
Regulation and guidance			
Transition guide for regulatory change Regulation (EU) 2021/1296	AESA	2022	[39]
Other material			
Monitoring Real-Time Environmental Performance	Boeing	-	[40]
Fuel monitoring on A320 Family aircraft	Airbus	-	[41]
Webinars			
1st Webinar on Fuel Management Rules	EASA	2022	[42]
2nd Webinar on Fuel Management Rules	EASA	2022	[43]

3.2.1 Regulatory framework for fuel management

Nowadays, sustainability is one of the most important trends in aviation and the aviation industry is increasingly committed using resources more efficiently. In that regard, regulatory bodies have recognized that their fuel planning requirements were becoming too conservative and prescriptive with recent developments in aircraft and engine reliability and with the great increase in data availability and accuracy. Thus, many regulatory bodies have adapted their fuel legislations and are giving more flexibility to operators in order to promote the optimisation of resources and make the air transport industry more sustainable.

In order to **enable the transition to digital fuel management**, EASA published the **Commission Implementing Regulation (EU) 2021/1296** on 4th August 2021, which amended and corrected **Regulation (EU) 965/2012** (the air operations regulation) as regards the requirements for fuel/energy planning and management, as well as other flight crew regulations. Additionally, EASA released the **ED Decision 2022/005/R**, which gives guidance to implement the new requirements introduced into the regulation by providing acceptable means of compliance (AMC) and guidance material (GM). The performance-based regulation has been fully detailed by merging safety objectives in the Implementing Regulation and a set of means to comply in the AMC.

The new fuel/energy regulations have several implications and direct impact on different stakeholders, mainly NAAs and operators. Specifically, flight crews, dispatch, performance department, navigations department and operations control are the most affected stakeholders within an airline. The **fuel standards** that were in force until 30th October 2022 were based on three (3) fundamental pillars, each of them being a different line of action for commercial air transport operators:

1. Fuel planning policy, which was performance based and required a prior approval by the competent authorities;
2. In-flight fuel management policy, which was prescriptive and did not require prior approval; and
3. Selection of aerodromes and planning policy, which was also prescriptive but did need prior approval for some parts.

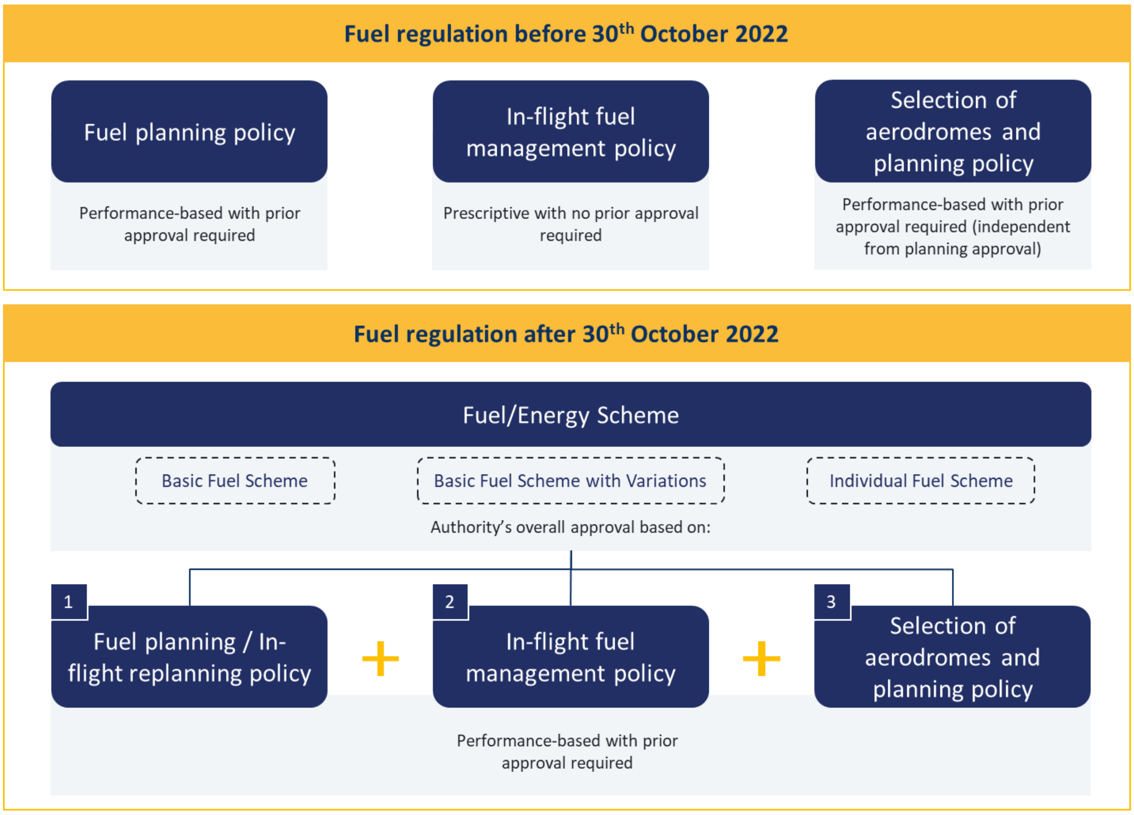
As seen, the previous regulation was largely prescriptive. Performance-based fuel planning was only allowed in a few cases and the flexibility it provided in the reduction of contingency fuel was minimal. With the new regulation in place, this has been reversed and much more flexibility has been given for contingency fuel reduction. Additionally, new regulations also apply for aircraft powered fully or partially by alternative energy sources, such as electric aircraft.

The main idea behind the new set of rules is to provide air operators with more flexibility regarding contingency fuel, the fuel required to compensate for unforeseen factors during the flight that can have an influence on fuel consumption. Reducing the amount of loaded fuel allows for reducing the total fuel burn as the fuel burn depends on the aircraft's weight. Thus, the final objective is to reduce the environmental impact of air operations and to improve the economic performance of operators by introducing three different fuel schemes:

- Basic fuel scheme, which is a prescriptive scheme similar to previous fuel regulations;
- Basic fuel scheme with variations, which allows the reduction of contingency and taxi fuel based on performance if specific requirements are met; and
- Individual fuel scheme, which allows the reduction of fuel based on operator's criteria if specific requirements are met.

Similar to previous rules, EASA defined 3 new pillars for each scheme: the planning and in-flight re-planning policy, the aerodrome selection policy and the in-flight management policy (see Figure 3-1). Each fuel scheme should be assessed on all three pillars separately and together in order to ensure a safe performance-based implementation of each policy.

Figure 3-1 Comparison between fuel regulations before and after 30th October 2022 based on EASA's webinar on fuel management [42]



Operators aiming to operate under a fuel reduction scheme are obliged to have a minimum Operator Control Capability (OCC). Airlines operating under the Basic Fuel Scheme only need to comply with ORO.GEN.110 while in the other two schemes, operators should have an OCC equivalent to flight monitoring, although it is recommended to implement the flight watch capability as it is the widest and safest option.

The detailed description that each OCC should contain is not available in the current regulatory framework. However, changes are foreseen through RMT.0739, which will deal with new requirements in the fuel management framework. The current available description of OCCs is presented in Table 3-2, based on definitions extracted from EASA Easy Access Rules for Air Operations [14]:

Table 3-2 Description of existing OCCs

Definition of Operator Control Capabilities			
Requirement	**Operator Control Capability**		
	Flight following	**Flight monitoring**	**Flight watch**
Recording in real time departure and arrival messages by operational personnel	Yes	Yes	Yes
Operational monitoring of flights throughout all flight phases	No	Yes	Yes
Communication of all **relevant safety information (RSI)*** between personnel on ground and flight crew **RSI is any element that may affect the safety of the flight, such as position reporting, aircraft technical failure, unforeseen hazards, updates of the operational flight plan when they affect the fuel reserves and other specific risks based on the SMS*	No	Yes	Yes
Critical assistance to flight crew in the event of an emergency, security issue or at request	No	Yes	Yes
Active tracking of a flight throughout all flight phases to ensure that the flight is following its prescribed route without unplanned deviations, diversions or delays	No	No	Yes
Required and recommended OCCs for each fuel scheme			
Basic Fuel Scheme	-	-	-
Basic Fuel Scheme with Variations	-	Required	Recommended
Individual Fuel Scheme	-	Required	Recommended

3.2.2 Basic Fuel Scheme

This fuel scheme is quite similar to previous fuel rules and has been established as the mandatory baseline for air operators. Therefore, most airlines are currently under this scheme and have **a prescriptive amount of contingency fuel** that should be 5 % of planned trip fuel or an amount to fly for 5 minutes at holding speed at 1,500 ft. above the destination aerodrome in standard conditions, whichever is higher.

Regarding the other fuel categories, all fuel calculations also remain prescriptive:

- Taxi fuel: computed according to APU consumption and local conditions at departure aerodrome, which include NOTAMs, meteorological conditions, ATS procedures and anticipated delays);
- Trip fuel: necessary fuel for take-off, climb, cruise, descent, approach and landing;
- Destination alternate fuel: fuel necessary to perform a missed approach, climb, cruise, descent, approach and landing at alternate destination;

- Final reserve fuel (FRF): an amount to fly for 30-45 minutes (depending on engines) at holding speed (1500ft);
- Additional fuel: an amount to go from most critical point of the route to ERA, hold 15 minutes at holding speed (1500ft), perform the approach and land;
- Extra fuel: computed according to anticipated delays; and Discretionary fuel: amount of fuel solely required by the commander.

There are **no special requirements for neither the authority nor the operator** to implement this fuel scheme. However, the new rules **promote the use of fuel consumption monitoring systems**.

3.2.3 Basic Fuel Scheme with Variations

By meeting specific additional requirements, operators can deviate fully or partially from the basic fuel scheme through this scheme by being able to reduce both contingency and taxi fuel if specific requirements are met.

On the one hand, the operator may **reduce the loaded contingency fuel**, which should be the highest of the following options:

1. An amount of fuel that should be either:
    a. not less than 3 % of the planned trip fuel; or
    b. an amount of fuel sufficient for 20-minute flying time based upon the planned trip fuel consumption; or
    c. an amount of fuel based on a statistical fuel method, named Statistic Contingency Fuel (SCF)
2. An amount of fuel to fly for 5 minutes at holding speed at 1,500 ft. above the destination aerodrome in standard conditions.

On the other hand, **taxi fuel calculation can also be performance-based** and the operator may also use statistical taxi fuel if requirements are met.

There are no special requirements for the authority. However, **the operator should fulfil the following requirements**:

- Establish and maintain a fuel consumption monitoring system for individual aeroplanes;
- Implement and maintain computerised flight plans;
- Have a continuous 2-year operation during which SCF data is recorded to implement the SCF method; and
- Select a fuel En-Route Alternate (ERA) aerodrome to reduce contingency fuel to 3%.

3.2.4 Individual Fuel Scheme

Finally, EASA presents the individual fuel scheme, which mostly applies for big operators with advanced monitoring capabilities already in place. The main benefit of this scheme is that the operator can load an amount of fuel for each aircraft/route combination based on its own criteria. If the operator is able to demonstrate the fuel consumption of each aircraft-route combination, the operator has complete flexibility to decide the amount of fuel it loads in such flights. Operators under this scheme might, for instance, reduce contingency fuel, compute trip fuel with statistical methods (Statistical Trip Fuel) or reduce any other fuel part according to own AMC.

This fuel scheme is the most advanced but also restrictive scheme, as it requires additional compliance and monitoring efforts. The operator must invest effort in analysing operational and security historic data to demonstrate that it has sufficient capacity to operate within an individual scheme. The implementation of this scheme has a major and transversal impact on the airline's internal processes. Therefore, it is important to make an initial assessment of the operator's capabilities before implementing an individual scheme.

Individual fuel schemes are **intended for CAT operators that want a scheme fully tailored to their operations and needs**. Under this scheme, operators may reduce fuel if they are able to demonstrate a set of operational and safety baseline performance. Operators aiming to operate under this scheme should fulfil the following requirements:

- Establish and maintain a fuel consumption monitoring system for individual aeroplanes;
- Implement and maintain computerised flight plans;
- Have a flight monitoring (minimum required) or flight watch (minimum advised) control capability;
- Have a continuous 2-year operation during which data is recorded and use it to demonstrate a baseline performance on agreed Safety Performance Indicators (SPIs);
- Have a safety risk assessment greater or equal to a certain level of safety;
- Perform the collection and continuous monitoring of reliable operating conditions, which include meteorological, aerodrome and traffic information (quality assurance in terms of accuracy and integrity);
- Personnel training including flight crew;
- Perform continuous reporting with competent authorities;
- Implement specific aircraft capabilities:
    - Fuel prediction system
    - Two independent airborne communication systems (e.g., VHF and SATCOM)
    - Centralised operational control system that allows the monitoring of the status of aircraft systems that affect fuel consumption and of ground and aircraft systems that affect landing capabilities
- Have the available infrastructure in the area of operation; and
- Implement and maintain organisational control, including processes and resources.

In addition, the approval of individual fuel schemes entails **new requirements and capabilities of competent authorities**. The competent authority is required to have qualified personnel with the necessary knowledge and expertise to understand, monitor, and validate the criteria of the new rules. Additionally, the competent authority is required to develop guidance material to be used by its inspectors when approving and verifying individual fuel schemes.

To sum up, RMT.0573 does not cover a single topic but touches many disciplines in flight operations and thus, it requires for a setup and implementation process across several departments within each airline. Changes introduced with this new regulation are numerous and have several implications and **direct impact on different stakeholders**, mainly flight crews, dispatch, performance department, navigations department and operations control. Some air operators have already identified all affected areas and are already working on developing internal policies that will allow them to scale up their fuel/energy scheme. This provides an important learning opportunity both for the operators themselves and for competent authorities, who are facing challenges to approve individual schemes.

In addition to this, further changes to the fuel management regulatory framework are foreseen, e.g., the introduction of new AMCs for the FRF through RMT.0392 [44], which is currently calculated on a prescriptive basis.

3.3 Digital capabilities and solutions

The implementation of this new regulatory framework sets the basis of the new 'fuel/energy schemes' concepts that will allow operators for more flexibility in fuel planning and management. However, this flexibility is due to performance reasons that cannot be defined or managed without a robust data-driven technology system. This is the proof that **digitalisation is becoming a powerful proxy for fuel optimization**, as well as for real-time flight control and interaction, effective cost and resources management, paperless operations and most important, enhanced safety procedures.

The previous section reviewed the regulatory framework governing the new paradigm shift in fuel management, and with it, the transition to a digital fuel management framework. At this point, the paper intends to focus on the set of digital capabilities and solutions that facilitate regulatory compliance, identifying a sample of the most relevant ones. The identified **key capabilities and solutions have been grouped by categories, depending on the requirement to which they ease compliance**. Moreover, solutions have been analysed and their main features summarised with the aim of providing a detailed vision of the state-of-the-art digital solutions that can help operators to implement each fuel scheme. Research reviewed as part of this analysis is included in Table 3-3.

Table 3-3 Research identified for CS4

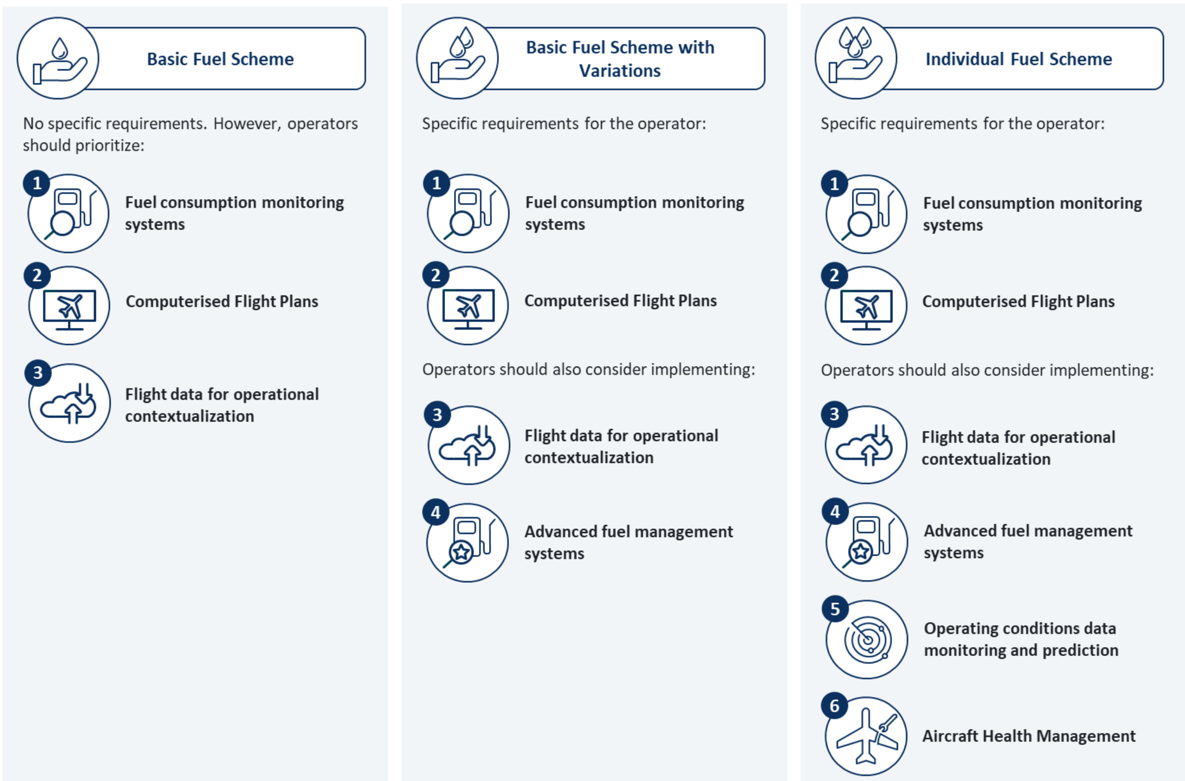
Case Study 4: Digital fuel management			
Paper Title	**Owner / Published by**	**Year**	**Reference**
Papers / Scientific studies			
Modelling of aircraft fuel consumption using ML algorithms	S. Baumann & U. Klingauf	2020	[45]
Improving airline fuel efficiency via fuel burn prediction and uncertainty estimation	L. Kang & M. Hansen	2018	[46]
Physics Guided Deep Learning for Data-Driven Aircraft Fuel Consumption Modelling	M. Uzun, M.U, Demirezen & G. Inalhan	2021	[47]
Cluster-Based Aircraft Fuel Estimation Model for Effective and Efficient Fuel Budgeting on New Routes	J. Yanto & P. Liem	2022	[48]
Flight Time Prediction for Fuel Loading Decisions with a Deep Learning Approach	X. Zhu & L. Li	2021	[49]
Prediction of Weather-induced Airline Delays Based on ML Algorithms	S. Choi, Y. J. Kim, S. Briceno & D. Mavris	2016	[50]
Flight delay prediction based on deep learning and Levenberg-Marquart algorithm	M.F. Yazdi, S.R. Kamel & S.J.M Chabok	2020	[51]
Characterization and prediction of air traffic delays	J.J. Rebollo & H. Balakrishnan	2014	[52]
Airline delay prediction by machine learning algorithms	H. Khaksar and A. Sheikholeslami	2019	[53]
Artificial intelligence prediction of air traffic flow rate at the Hong Kong International Airport	K. Hon	2021	[54]

Case Study 4: Digital fuel management			
Paper Title	**Owner / Published by**	**Year**	**Reference**
A Deep Learning Approach for Short-Term Airport Traffic Flow Prediction	Z. Yan, H. Yang, F. Li & Y. Lin	2021	[55]

The ultimate objective is to characterize the digital foundations that support the application of the new fuel schemes, serving as a basis for identifying potential development points or missing gaps in both regulations and digital capabilities, to be studied in greater detail throughout the project.

Figure 3-2 shows, for each fuel/energy scheme, the set of solution categories that are mandatory, those that are recommended to be implemented in order to access more advanced fuel/energy schemes and those that could provide an extra-mile in terms of fuel/energy planning and management. The rationale under this Figure is further developed in the following subsections, where specific digital solutions are presented for each category.

Figure 3-2 Graphic cross-reference between fuel schemes and digital solutions' categories



3.3.1 Fuel consumption monitoring systems

As stated in the new regulation, operators aiming to implement a fuel reduction scheme should establish and maintain a fuel consumption monitoring system. Thus, among all digital solutions identified, operators should **prioritize implementing a fuel consumption monitoring system in order to scale or upgrade their fuel scheme**. These systems allow airlines to gather the required two years of data for each aircraft and to demonstrate a baseline performance on agreed SPIs, which are basic requirements in order to access both the Basic Fuel Scheme with Variations and the Individual Fuel Scheme. According to ED Decision 2022/005/R [38], a fuel consumption monitoring system should be data driven and should include:

- Fuel performance monitoring system;

- Database that contains statistically significant data of at least 2 years;
- Statistics and data normalisation; and
- Data transparency and verification

Beyond providing the capabilities required to demonstrate the performance baseline and thereby meet regulatory requirements, the use of fuel monitoring systems bring **additional benefits to operators**, as:

- As more and more data is gathered, operators start to be aware of the fuel consumption of each aircraft and are able to start planning a tailored fuel monitoring and planning policy, as well as to find saving potentials.
- Operators can perform weekly monitoring of both taxi fuel and APU consumption and might be able to reduce taxi fuel in the future by means of Statistical Taxi Fuel Calculation (Basic Fuel Scheme with Variations and Individual Fuel Scheme).
- Operators can use monitoring systems to enhance pilot's engagement with fuel policies. Once pilots are fully aware of fuel consumption on their own flights, they might identify areas of improvement and reduce fuel consumption on specific manoeuvres. Additionally, once a considerable amount of data is gathered, planned fuel is more accurate and pilots might increase their trust in operational flight plans. Thus, pilots might be able to compute more accurate discretionary fuel amounts.
- Operators can also use these monitoring solutions for EU emissions trading system reporting, mandatory for all operators.

Most solutions on the market provide these capabilities and are integrated into operators' current policies and processes. The most relevant solutions that are already operative on the market are, in general, a suite of applications or a platform that include several modules in order to help airlines to build and grow a fuel efficiency programme with a single tool. Most digital solutions allow operators to analyse historic fuel consumption data and to estimate the right amount of fuel to load in a more accurate way. Additionally, most solutions include data analytics module that enable the identification of fuel-saving opportunities, as well as to monitor progress and take action. Furthermore, some specific solutions allow the integration of data sources (e.g., operational data, flight plans, QAR, weather data, etc.), which enables better decision-making processes to reduce fuel consumption, emissions and costs. Finally, some of them integrate an EFB application that provides real-time support and recommendations for fuel saving during the flight.

3.3.2 Computerised Flight Plans

In addition to fuel consumption systems, optimised flight planning software is an additional key capability to be developed by airlines for the approval of a contingency fuel reduction scheme, as it is required in both the Basic Fuel Scheme with Variations and the Individual Fuel Scheme. For instance, the aerodrome selection policy states that if the operator's fuel plan includes an isolated aerodrome, the Point of No Return (PNR) should be determined through a computerised flight-planning system. Additionally, variations to the basic fuel schemes in regard to the planning minima also require the use of these systems.

The regulation does not include a detailed description of the requirements regarding the software to be used for computerised flight plans. Rather, the regulation provides that operators should agree these requirements with the competent authority. By way of example, an operator should agree with his Authority whether flight planning software should include an aerodrome selection functionality or, conversely, this is a capability that can be channelled through alternative in-house analysis methods.

Beyond the minimum capabilities required for regulatory compliance, these digital solutions also provide operators with several opportunities for fuel and cost optimization by enabling them to:

- Merge data from different sources (e.g., METAR, NOTAMs, delays, etc.) in order to obtain more dynamic and accurate flight plans (useful to comply with Individual Fuel Scheme requirements regarding the collection and continuous monitoring of reliable meteorological, aerodrome and traffic information);

- Add time-based information and keep flight dispatchers, pilots and crew informed at tactical phases, for instance the update of flight plans when they affect fuel reserves (useful to comply with flight monitoring requirements in advanced fuel schemes);
- Automatically define several routes, altitudes and speeds at each flight phase for which fuel consumption is optimized and rank each scenario by specific KPIs;
- Automatically nominate a fuel en-route alternate airport for contingency fuel reduction (useful to comply with ERA requirements);
- Automate several processes and reduce dispatchers' workload; and
- Compare flight plan values to actual flight data, identifying discrepancies and potential improvement areas.

Most state-of-the-art flight planning solutions allow the automation of the flight planning process and its optimization. A wide array of information (such as weather and GPS data coverage validation, notices issued by meteorological agencies and aviation authorities) is fed to the algorithm to produce optimal and compliant plans that support dispatchers to evaluate the optimal route while taking current flight-related data into account. Some of these solutions can be easily used in advanced fuel policies, as they account for specific requirements such as the Missed Approach and Alternate Fuel Requirements.

3.3.3 Flight data for operational contextualisation

As of today, several national and international regulation organisations have introduced a set of requirements and recommendations related to the implementation of Safety Management Systems (SMS) by operators. Most regulations require specific CAT operators to **record flight data and to establish and maintain a flight data monitoring programme as part of its SMS**. This is the case in EASA Member States, where the implementation of a Flight Data Management (FDM) programme is mandatory as established in Commission Regulation (EU) No 965/2012. Additional discussion on the regulatory framework for FDM can be found in Section 4, which focuses on the case study on this topic.

Although the use of COTS solutions to collect flight data is already a common practice, many operators still face challenges in effectively using collected data to support their safety-related processes. For this reason, EASA is focusing its efforts in identifying all the relevant processes that may benefit from the analysis of flight data and **promoting the use of flight data not only in SMS but also in other safety-related processes**.

The entire fuel management and planning operation is a clear example of an application in which flight data can provide great value, underpinning many of the requirements established in the new regulation as well as opening new windows of opportunity for the future (e.g., contribution to fuel prediction and optimization). In this case, **both operators and authorities can benefit from such data for the implementation of the new regulation**.

On one hand, operators can rely on flight data to implement contingency fuel reduction schemes, which in turn implies that operators must implement and maintain more specific and demanding control capabilities. Indeed, flight data recorded in the Quick Access Recorder (QAR) or other equipment used for FDM programmes is necessary to fulfil the analysis of the operational environment and to safely implement performance-based schemes. Alternative positioning messages, as it is the case of ADS-B, could also fulfil this function and, additionally, could help implementing OCCs, as they can be transmitted in near / real-time..

The systemic collection and consolidation of this data can provide valuable information that can feed into the development of contingency reduction schemes, especially in terms of ensuring minimum safety levels. In this sense, the benefit is mutual for the airline and the Authority, being a very relevant source of data for the definition of safety indicators that build the necessary safety cases to justify individual fuel schemes more limited to the performance of the specific operation. Last but not least, this data is a valuable asset for the industry's collective knowledge and awareness. Through the participation and sharing of flight data in the context of industry-wide data exchange programmes (such as EASA Data4Safety or FAA ASIAS), the industry can benefit from standardised results and advanced post-ops analysis in order to establish and monitor their safety baseline performance. Undoubtedly, this collective effort and knowledge opens the opportunity for a potential standardization of the criteria established for the evaluation of safety levels in the application to reduced fuel schemes or even, a framework of collaboration and knowledge that promotes tools under which the application to reduced fuel schemes is facilitated.

In that regard, several state-of-the-art software have been identified. Most of them allow fully automated process for data gathering, distribution and real-time flight alerting, as well as to monitor flights on their en-route progress up until flight termination.

3.3.4 Advanced fuel management systems

Fuel performance monitoring solutions are traditionally and essentially data analytics platforms that allow the monitoring of fuel consumption in a post-ops environment. These monitoring activities enable operators to perform statistical predictions of fuel consumption for specific aircraft-route combinations, providing the basis for achieving the most demanding fuel optimization schemes, such as the individual fuel scheme. However, the market trend and progressive research is to evolve towards a more proactive and predictive environment, relying on Artificial Intelligence algorithms (e.g., Machine Learning).

This type of technology has proven to be very useful in different industries, especially in the development of capabilities that support decision making, as well as predictive algorithms. The advantages of these algorithms are multiple, as well as their scalability, their ability to manage and infer relationships in a multi-dimensional and multi-variable data environment and a wide range of possibilities for continuous improvement. The solutions and studies presented in this category are based on **Machine Learning (ML) algorithms to obtain fuel consumption predictions** and thus support decision making within reduced contingency fuel planning. This enables operators to make tactical decisions that allow **moving from reactive methods in post-operations to real-time predictive capabilities.**

Although most of the solutions presented within this category are studies that are not yet operational and available in the market, the large amount of research in this field indicates that the industry is moving towards this direction. In this regard, the implementation of ML algorithms may have an impact on existing regulation and, potentially, may require new standards or mechanisms that provide adequate confidence in the functioning of AI/ML applications when demonstrating compliance with requirements. Elements such as the integrity of the results of the algorithms, based on their criticality, traceability and ethics in their training are key components to be managed in the future. In fact, EASA has already taken a holistic approach to the issue by means of **EASA's Artificial Intelligence (AI) Roadmap**. Specifically, the first phase of the project has resulted in the publication of the "Exploration and first guidance development", a concept paper that presents a first set of objectives for Level 1 AI (assistance to human) to anticipate future EASA guidance and requirements for safety-related ML applications [56] .

A set of fuel prediction/optimization solutions and studies have been identified, as well as algorithms aiming at **predicting flight times** with the aim of increasing the accuracy of fuel consumption estimation and prediction. Most solutions under research are aimed at predicting and optimizing the efficiency during all flight phases, reducing fuel burn and carbon emissions through the application of ML algorithms (e.g., Neural Networks, Decision Trees, Random Forests, kNN, etc.) and ensemble learning techniques (combine the prediction results of different ML algorithms to obtain more accurate predictions). Results of most papers show accurate results, even when compared with state-of-the-art solutions already in place.

3.3.5 Operating conditions data monitoring and prediction

Regardless of the fuel scheme, **operators should always ensure that the planning of flights includes the most accurate operating conditions under which the flight is to be conducted,** which ultimately should be used as an input to progressively more accurate and complex fuel planning capabilities. The monitoring and prediction of operating conditions is relevant for all operators, as they should always consider anticipated delays and specific operational constraints in order to compute the extra fuel. Additionally, operators aiming to apply an individual fuel scheme shall monitor operating conditions, which shall include at least aircraft fuel consumption data, anticipated masses, anticipated meteorological conditions, the effects of deferred maintenance items, the expected route and runways and anticipated delays.

The monitoring and prediction of operating conditions data is a required capability that implies the acquisition of relevant exposure data and algorithms for managing, integrating and merging this data so that fusion data provides a complete picture of the operational environment. This is a key capability for operators to demonstrate a baseline performance under which fuel reductions are justified. In the future, these predictive capabilities will be critical, especially if new AI methodologies and algorithms start to be incorporated.

This category of digital capabilities aims to **group together all the solutions that allow improving the accuracy of the information that intervenes in flight planning** and that has not been dealt with in previous categories. Thus, this category is focused on **operating conditions data monitoring and prediction** solutions.

Apart from being useful information for flight planning and in-flight replanning, the prediction of operating conditions data also allows operators to:

- Perform more accurate calculations of taxi fuel, as taxi fuel should account for local conditions (i.e., meteorological conditions, ATS procedures, NOTAMs and any anticipated delay);
- Perform more accurate predictions of unforeseen factors considered in contingency fuel calculations (i.e., deviations from expected meteorological conditions, extended unexpected delays in flight...);
- Perform data-based decisions when in-flight re-planning is necessary (e.g., being obliged to change the intended course of action due to safety issues or weather conditions); and
- Finally, when applying for an individual fuel scheme, operators should have the capability to monitor the reliability of meteorological forecast reports. To this end, tools to predict and improve the reliability of the meteorological forecast reports allow operators to ask for intended deviations.

Most digital solutions aimed at operating conditions monitoring are tools that provide trajectory optimization based on flight data as well as weather, Air Traffic Control (ATC) restrictions and delays, among other data sources. In addition, some solutions also include the current evaluation of weather along the route and provide detailed forecasts to generate weather briefing reports for each flight.

On the other hand, several solutions have been found under research. Most scientific studies aim to develop prediction models to classify delays caused by adverse weather, to predict and characterize flight delays based and to predict air traffic flow rate.

3.3.6 Aircraft Health Management

EASA's new fuel regulations establish that operators aiming to implement an individual fuel scheme should establish and maintain operational control capabilities that allow the **monitoring of aircraft systems that affect fuel consumption** (AMC1 CAT.OP.MPA.180). These capabilities enable operators to assess the reliability of fuel-related systems and take corrective actions if necessary, as well as to monitor fuel consumption over time and potentially relate increases in fuel consumption to possible system degradations. In this regard, operators can benefit from Aircraft Health Management (AHM) systems, which are defined by IATA as "the unified capability of using health monitoring of aircraft structure and systems (including propulsion system) to control the scheduling of aircraft needed maintenance actions". By implementing diagnostic, prognostic, and health management methods, it is possible to increase system dependability and lower aircraft operating costs, becoming a vital part of safe aircraft operation and maintenance. The integration of AHM digital solutions in maintenance procedures and policies allow operators to make data-driven maintenance decisions, optimizing maintenance activities and schedule, as well as to identify trends to support long-term fleet reliability programmes. AHS systems are progressively including soft computing methodologies such as Artificial Intelligence algorithms, to estimate the health status of systems, as it could be the future performance of the fuel system. A complete AHM system can be deployed to support the performance monitoring of fuel-related aircraft components, as it could be the monitoring of the signals generated by controllers to the fuel tanks based on the fuel requirement of engines, and potentially detect future faults or degradation of fuel systems. In other words, these systems allow operators to **better determine the extent of the deviation from the current fuel scheme by assessing the reliability of the aircraft systems**, especially the time-limited ones. This is fully aligned with the requirement set forth in AMC1 CAT.OP.MPA.180, which establishes that those operators aiming to scale up their scheme to an individual fuel scheme should establish an operational control system that allows the **monitoring of the status of aircraft systems that affect fuel consumption** and of ground and aircraft systems that affect landing capabilities.

Some of the key state-of-the-art AHM solutions are data platforms that combine in-flight, engineering and operational data to allow airlines addressing aircraft operational challenges. Most of them use predictive tools to determine the aircraft's status of future serviceability and performance. In addition, some solutions include real-time fault alerts, which allow the operator to make real-time maintenance decisions and to increase operational efficiency.

3.4 Conclusions

The new regulatory framework is the starting point for the transition to digital fuel management, which will allow operators for more flexibility in fuel planning and management. Nevertheless, this flexibility must be supported by the implementation of robust digital capabilities that enable the application of specific fuel schemes and serve as a basis for defining and implementing new data-driven decision processes to reduce fuel consumption, CO_2 emissions and in consequence, airlines' operational costs.

In that regard, a set of digital capabilities has been identified that enables operators to meet the requirements of the new regulatory framework and brings multiple benefits, such as:

- Enhanced data gathering processes, which allow operators to start defining a tailored fuel monitoring and planning policy, as well as to find saving potentials;
- Enhanced decision-making capabilities for both operators and pilots, which allow for the increase of operational performance without compromising safety;
- Enhanced fuel monitoring capabilities, which enable the reduction of carried fuel and thus, the reduction of fuel consumption and emissions; and
- Reduced workload in terms of analysing data and drawing conclusions.

However, as the usage of modern digital solutions advances, new challenges and limitations arise, such as:

- **Need of standards regarding collection and management of data for performance-based schemes**: Operators aiming to implement the Basic Fuel Scheme with Variations or the Individual Fuel Scheme need to gather two years of data for each aircraft-route combination to demonstrate a baseline performance. However, the standards regarding both the collection and management of data are not fully defined.
    - On one hand, guidance material states that the required database should contain statistically significant data but there are no consolidated requirements regarding the minimum set of data for each aircraft-route combination taking into consideration the operators' size and operational capacity.

- On the other hand, there is also a lack of standards regarding the management of such data, which is necessary to establish a periodic monitoring of the implemented fuel scheme to ensure that safety is not compromised at any level and that fuel planning and management processes are fully updated. In this regard, there is the need of standardised key performance indicators (e.g., data integrity or accuracy) that allow operators to adopt data management processes with minimum levels of quality. In addition, data management processes also lack detailed standards regarding data normalisation, transparency and verification.
- Additionally, alternative energy sources (e.g., electric energy) have been introduced into the new regulatory framework. However, the regulation lacks specific requirements, which may lead to new problems as electrical energy has different needs. In this regard, additional guidelines should be developed for the collection and processing of data in these cases.

- **Lack of mechanisms to adopt an ecosystem of digital solutions**: In order to implement fuel reduction schemes, certain digital capabilities and solutions need to be adopted. This brings two different potential challenges. First, regulation does not specify minimum functional requirements for certain digital solutions. For instance, regulation does not give any detail on whether computerised flight plans should include specific modules such as ERA selection or not, which can make it difficult to choose solutions that suit the expectations of competent authorities when approving fuel schemes. Another clear example is the lack of details regarding Operator Control Capabilities. The definition of detailed requirements for each OCC would allow either the adoption of a centralised system in which all control capabilities are integrated or an ecosystem of modular solutions that complement each other (e.g., flight tracking systems based on ACARS or ADS-B, instant communication applications, etc.). In both cases, requirements should be defined to ensure minimum levels of safety in terms of control capabilities. Secondly, the adoption of these state-of-the-art ecosystems may require new technical standards in order to ensure the integrity of the procedures and results, as well as additional digital solutions and processes to be managed in the future (e.g., AI/ML algorithms for fuel prediction).
- **Missing guidelines for safety indicators definition and calculation:** The definition of safety indicators serves as a basis for building the safety cases necessary to justify fuel reduction. The lack of guidelines for the definition of such indicators as well as for the calculation process or pseudo-codes makes the standardisation of indicators between operators difficult and therefore the approval of each scheme requires more effort by the competent authorities. In this regard, there is the need of detailed guidance material that defines specific indicators and that considers the operational context (e.g., number of flights, OD combinations, etc.). In addition, it is possible to take advantage of data exchange programmes to see how such initiatives can fit in with the facilitation of the safety baseline, especially for Individual Fuel Schemes.
- **Incipient status of data sources fusion capabilities:** The adoption of reduced fuel schemes requires the acquisition and monitoring of different data sources such as operational data, maintenance data, NOTAMs and traffic information, among others. This requires the adoption of algorithms for managing, integrating and merging this data so that fusion data provides a complete picture of the operational environment and a more robust performance of analytical platforms. In this regard, operators would benefit from efficient data management solutions integrated into daily operations to enable data-driven decision-making processes. Although there are some data processing, modelling and fusion strategies applied in the aviation sector, the state of data fusion techniques in relation to fuel management is incipient and further developments are required. For this reason, new needs may arise regarding standardised approaches in which industry moves forward together to develop such capabilities.

4. Case Study 5: Flight data models for safety

4.1 Introduction

Effective safety management within the aviation industry depends on the creation and combination of various technical, operational and human conditions. The underlying factor, however, is risk management driven by safety intelligence, a key component of which is flight data [57].

Flight data recorded by the internal sensors of the aircraft is a unique source of information on the state of the aircraft and its components, on the interactions of the pilot, and of the interactions of the aircraft with its surroundings. Despite the existence of alternative sources of information on the state of the aircraft, such as Automatic Dependent Surveillance Broadcast (ADS-B) / Secondary Surveillance Radar (SSR) for aircraft-environment interactions, they present significant limitations. Not all data may be available in an adequate format, availability may depend on external devices with limited data capturing range (radar, antennas), or data may not be exhaustive enough. Additionally, no alternative exists to internal flight data on the state of the aircraft and its components. As such, flight data recorded within the aircraft remains unique by incorporating information on all these areas.

Historically, flight data was utilised in the context of safety investigation through the usage of Flight Data Recorders (FDRs), but the transition from reactive to proactive risk management (and, for some organisations, predictive risk management) has entailed the usage of flight data in Flight Data Monitoring (FDM) programmes within, primarily, aircraft Commercial Air Transport (CAT) aeroplane operators. In parallel, however, the availability and reliability of flight data, coupled with the increased affordability of data processing and storage, has popularised applications outside FDM programmes that can help in operating safely and efficiently, expanding the number of safety-concerned stakeholders interested in access and usage of the data. Nonetheless, some of these applications will not have flight data processing capabilities integrated, requiring the usage of use flight data previously processed within an FDM programme.

In this Literature Review for Case Study 5 the concept of the FDM programme is explained, followed by a review of other applications of flight data inside and outside the operator. An overview of the regulatory framework under which FDM programmes are currently piloted is presented as a means to understand the requirements currently placed over FDM programmes. To conclude, digital capabilities and solutions that may be used for addressing these requirements and proposed by private companies, institutions and academia are described, to be used as a baseline for the development of the Case Study.

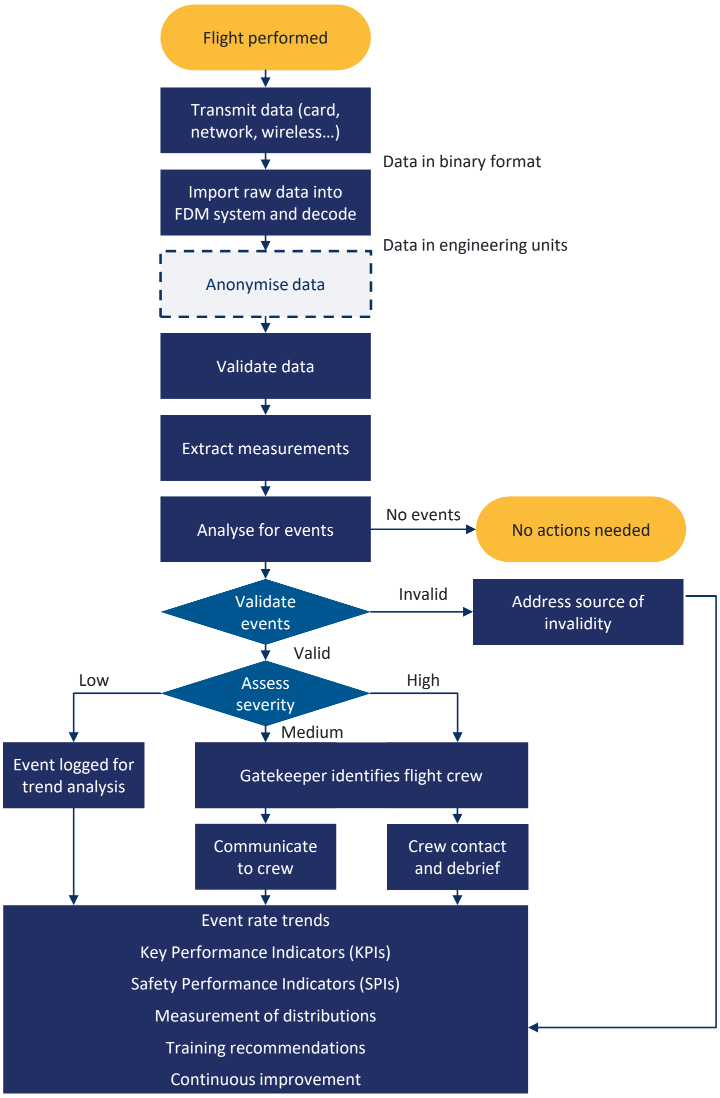
4.1.1 The FDM programme

Flight Data Monitoring (FDM) means the proactive and non-punitive use of digital flight data from routine operations to improve aviation safety [14]. In order to systematise this task, operators set up programmes where flight data is routinely analysed and that must be integrated into the operators' management system, also referred as the Safety Management System (SMS).

A FDM programme should allow an operator to: assess safety risks through the identification of areas of operational risk, quantify these risks by identifying occurrences of unusual/unsafe circumstances (recording their frequency and severity), and determining when an operational risk becomes unacceptable based on the trends of occurrences observed (see AMC1 ORO.AOC.130 [14]).

Given the aforementioned objective, the key stages of an illustrative FDM process can be summarised as shown in Figure 4-1, without including the interaction with the SMS procedures:

Figure 4-1 Example of FDM process, adapted from [59]



Once the flight has been performed and **data recorded** into a Quick Access Recorder (QAR) or a similar device, **data** is **extracted** from the aircraft and transmitted (either physically through the removal of the storage device from the aircraft, or the automatic download via secure wireless systems) to a ground-based computer system incorporating FDM software (managed by the operator or through a Software as a Service (SaaS) web interface) [58]. Given the historical memory limitations that QAR and similar devices contended with, data is recorded in a binary format and **decoded** into engineering units with the aid of the Logical Frame Layout (LFL).

Depending on the de-identification policy at the operator, data may be **anonymised through de-identification** before further processing occurs, to ensure nondisclosure of identified flight data when not required and avoid uncontrolled access to it. A re-identification methodology must exist for cases where an event is deemed a continuing unacceptable safety risk which requires specific action, or for dissemination of information to flight crews on their general or particular safety performance [58]. Such dissemination can be automated in a confidential manner [60].

The processing step of flight data entails validating the data, performing measurements, detecting events and validating these events, with the first usually automated through the FDM software, and the latter performed by an analyst.

Data validation is concerned with assuring the quality of flight parameters before any measurements or events are detected. Typical quality problems include sudden variations to abnormal values, missing or frozen parameters due to system malfunction, value bias due to calibration issues, etc. [61]. Once data is validated, **measurements** are performed to characterize flights and perform comparative analysis of operational statistics which may or may not be directly linked to a safety event (e.g., maximum rate of descent, landing weight, go-around altitude, autopilot status at touchdown) but are useful in understanding the context of operations and may be used to detect emerging trends before trigger levels associated with FDM events are reached.

Afterwards, **FDM events are identified** by detecting when a flight parameter or combination of such surpass the thresholds associated with the event algorithm. During the algorithm definition phase, testing is necessary to ensure the correct definition of the logic and that the defined threshold value is adequate to the purpose of event detection. The testing may include usage of past operational data with known occurrences (from the occurrence reporting system) to check for correct events and false negatives, and usage of a "control set" to ensure minimal false positive reporting [61] Thresholds can be selected in various ways [62], such as:

- airworthiness or other physical or maintenance-related limits (AFM, AMM or other OEM documentation);
- internal procedures (standard operating procedures (SOPs)), or external or industry recommendations (if not transposed into SOPs);
- detection of outliers (using measurement distributions)

Once the algorithm is operational, the operator needs to **validate the individual FDM events** that are being generated. False positives can still occur as a result of faulty data or noise and require the refinement of the algorithms used for data validation. But they can also occur when there is a high rate of events. In this case, it's possible that the threshold wasn't established with a suitable value and has to be re-evaluated [62]. Not every FDM event is manually validated, as there may be too many low-severity events for individual validation.

Assessing the severity of any particular event is usually performed by the analyst in conjunction with the event identification algorithm. The establishment of multiple severity thresholds for a particular event is particularly useful in categorizing the event, as it helps the analyst in highlighting certain events, keeping in mind that a high severity event does not imply a high operational risk [59] To better analyse the actual operational risk, it is always necessary to contextualize an event with qualitative information and follow an established risk assessment methodology. Contextualization may include accessing other sources of data, such as safety reports, weather data, traffic data, data on the runway, on surrounding terrain and obstacles, NOTAMs, etc. Such information gathering may be performed automatically or manually, and from involved or uninvolved parties (safety reporting), or may require direct contact with the flight crew, engineering or other operational staff, in which case the role of a Gatekeeper (safety manager, agreed flight crew representative, honest broker) serves as a guarantee that access to identifiable information remains restricted [58].

For those events deemed an unacceptable safety risk and which require a corrective action, a proper investigation is required. When attributed to deficiencies in pilot handling technique, the information, de-identified, is passed on to the Gatekeeper, who is charged with **contacting and debriefing the specific crew member** and obtaining feedback. These actions may include re-training, revisions to manuals, changes to ATC and airport operating procedures [14].

Additionally, **metrics can be computed** over the whole database of events and measurements, as much of the benefit of FDM comes from analysing very large numbers of flights to look for trends in the operation [61] The production and analysis of event rates, trends over time and event and measurement distributions are used to complement and interface with the Safety Management System (SMS) of the operator (e.g., Safety performance indicators (SPIs) to monitor precursors relevant to a particular operational risk).

Flight Data Monitoring (FDM) programmes must be integrated into the Safety Risk Management (SRM) process, an essential process of an operator's Safety Management System (SMS), through the identification, quantification and the assessment of operational risks. The FDM programme may play a particular role among

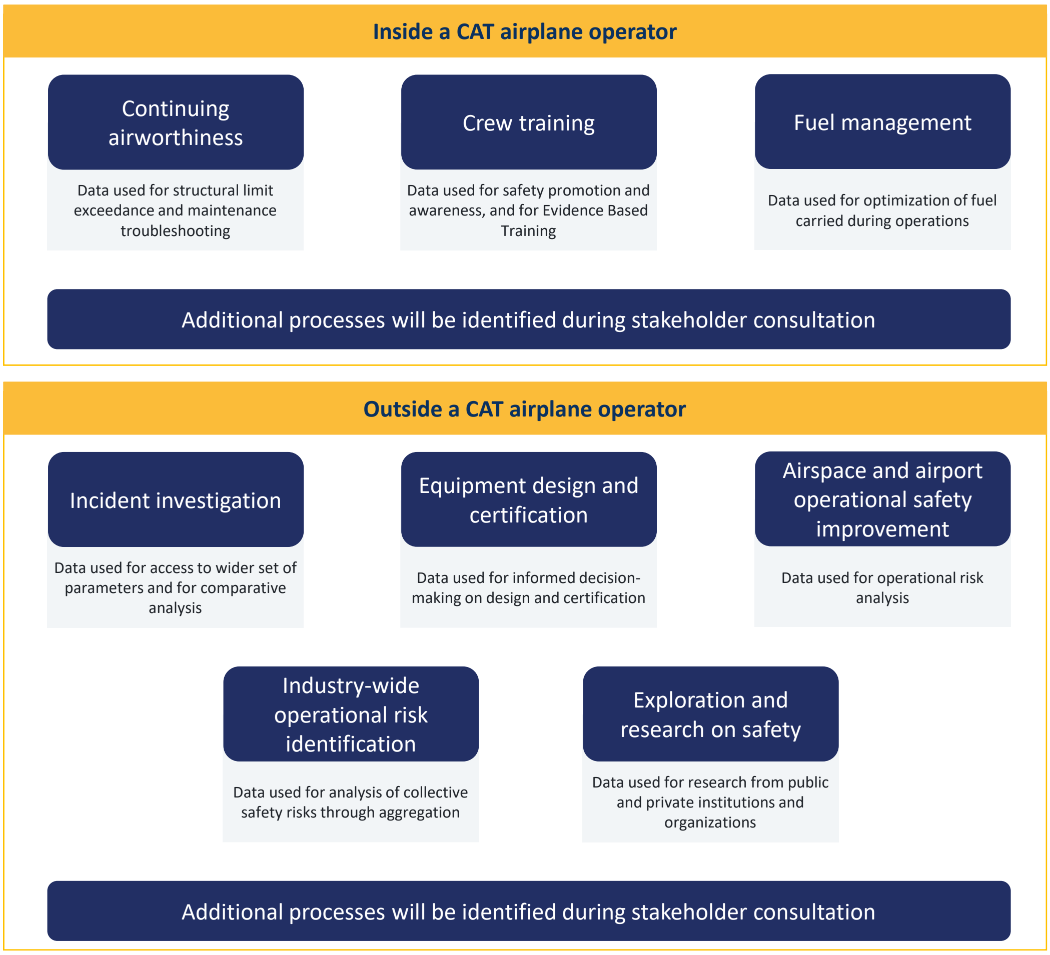
SMS data sources because it has the potential to capture all flight operations, recording every measurement or deviation and supporting accurate reconstruction of incidents. Integrating the FDM programme into the operator's management system allows for a better analysis of events, addressing practical questions regarding safety trends and supporting safety decision-making.

4.1.2 Using flight data outside FDM

Flight data has additional utility on safety-relevant processes inside and outside the operator, as the factual information on the flight performance contained by the data is not available anywhere else. Its usage entails going beyond the conventional use of FDM and serving internal and external 'customers' in the discharge of their safety duties [60] The concept of using flight data for safety-relevant processes outside the well-trodden path of FDM programmes is the basis for one of the fundamental objectives of this Case Study, to investigate the development of comprehensive data models "bridging" the gap between the flight data sources and their many current and potential uses (both internal and external to the operator).

Figure 4-2 shows, inside and outside the operator, the set of safety-relevant processes that can benefit from the usage of flight data internally captured by the aircraft. A more detailed description of each of the processes is developed in the following text.

Figure 4-2 Safety-relevant processes that may benefit from flight data



More data-driven information might be beneficial for all departments within an operator since it would increase each department's awareness of safety issues, efficiency, or perhaps both. To do this, it is essential to fully comprehend the requirements of the SMS stakeholders as well as other internal customers related to safety, and it may also be necessary to inform them of the value of flight data and the significance of protections to secure it. Safety-relevant processes within the operator that can benefit from flight data include:

- **Continuing airworthiness monitoring**: Maintenance departments and organizations are tasked with ensuring the airworthiness of the aircraft under their purview. Flight data can be used to identify critical maintenance tasks by reporting situations when a structural limit exceedance is suspected, or for preventative measures that ensure the aircraft's continuous airworthiness, supporting maintenance troubleshooting (i.e., Engine Health Monitoring or Aircraft Performance Monitoring). In the context of supporting maintenance troubleshooting, the monitoring of the quality of flight parameters sent to both the FDR and QAR from the FDAU can be used to detect issues and ensure serviceability of the hardware [58]
- **Crew training**: FDM data can support training processes towards improvement of safety promotion and awareness. Technical capabilities of FDM and flight operations teams may be combined to generate flight animations that can help crews get more comfortable with aerodromes, improve awareness of unexpected aircraft/system behaviour and supplement other sources of mitigating action, such as operating procedures, training, etc. Flight data can also support Evidence Based Training (EBT) programmes, where pilots are exposed to unexpected scenarios in their training in order to develop critical core competencies in both technical and non-technical areas. EBT programmes are based on the analysis of a large and comprehensive set of reference data, including flight records and FDM data so as to identify and assess the risks faced during real operations and, as an outcome, to develop tailored training programmes to mitigate those risks (see Case Study 3: Flight training data for EBT/CBTA for more information)
- **Fuel management**: A transition to digital fuel management systems is ongoing, which allows operators to develop a detailed fuel monitoring capability over different time horizons, as well as to introduce potential optimizations in the fuel carried during operations. These optimizations, however, can never occur at the expense of a reduction in safety levels. It is crucial to ensure that aircraft carry enough fuel to ensure the safety of operations in case of unforeseen events, such as delays on approach to the destination airport or landing impossibility due to weather conditions. Within this context, EASA has released new regulation to enable the transition to digital fuel managements. Among the newly established requirements flight data can be used to implement the Operator Control Capabilities (OCC) required in contingency fuel reduction schemes (i.e., flight monitoring and flight watch, see Case Study 4: Digital fuel management for more information).
- **Additional safety-relevant processes** within the operator will be identified during the consultation of stakeholders.

Other safety-relevant processes performed by other members of the aviation safety ecosystem may also benefit from flight data captured by the operator, including:

- **Safety investigation**: As a fully functional process within the safety ecosystem, safety investigation uses internal flight data usually extracted from the Flight Data Recorder (FDR), which unlike the Quick Access Recorder (QAR) has been specifically designed to support the accelerations and temperatures of an aircraft collision. Even so, QAR-recorded data can be useful in safety investigation in two ways: First and foremost, incidents can benefit from its expanded set of recorded parameters in comparison with the FDR. Secondly, flight data can be used for comparative analysis, either for the same aeroplane in previous operations, or for other operations following the same flight path, aiding in contextualization and understanding of the incident.
- **Equipment design and certification**: Original Equipment Manufacturers (OEMs) and National Aviation Authorities (NAAs) benefit from understanding aircraft and fleet performance, which can include information on loads sustained, typical operation, environment conditions and its impact on the aircraft, etc. The analysis of aggregated flight data can aid CAAs in performing more informed decisions on technical requirements for certification, and similarly help OEMs with designing products better

adapted to the needs of their clients based on their operational performance and the environmental conditions they most encounter, overall improving safety.

- **Airspace and airport operational safety improvement**: Airport operators and Air Navigation Service Providers (ANSPs) usually operate systems or execute procedures to capture and register information on the operations being performed within their scope of responsibility. Still, the data they capture may be limited in terms of its content or regularity, such that its applicability to risk-factor analysis is limited. Flight data, with its high rate and wide number of parameters recorded can allow airport operators to better understand the actual operation within the airside of the airport, with precise, timestamped data on the position, heading, speed or engine power of each aircraft, enabling risk identification and quantification (e.g., analysis of actual critical jet blast points in taxiways). ANSPs, on the other hand, can benefit from the fusion of their own data (e.g., SSR, Air Traffic Controller (ATC) communications) with operators' flight data, as a method to evaluate and quantify operational risk derived from pilots complying with specific commands from the ATC.
- **Industry-wide operational risk identification**: While aircraft operators use their FDM programmes to identify and quantify areas of operational risk for their own operation, the industry as a whole can collaborate on identifying common operational risks through the aggregation of flight data from operators across the industry. This allows for the identification of operational risks which may not have been clearly visible for each operator individually (e.g., airports with a particular approach with irregularly scheduled operations, such that trend and event analysis for a single operator is not representative enough). Additionally, it allows operators to compare their risk patterns with those of other airlines, helping assess and rank safety risks. Ongoing programmes such as the Data4Safety (D4S) are concerned with these processes (see section 4.3.1.)
- **Exploration and research on safety**: Scientific research in the field of safety, and particularly for aviation, is a key endeavour for the continuous improvement of the tools and methods available to risk managers. Many topics are being researched with flight data at its core, from the usage of Artificial Intelligence (AI) algorithms for anomaly detection or for automatic FDM event and threshold definition, to assessment of fatigue impact on operational performance through the fusion of flight data with bio-mathematical models, to the safety evaluation of free route airspace deployment. For these and many other research initiatives, the availability of flight data is a key factor.
- **Additional safety-relevant processes** within the operator will be identified during the consultation of stakeholders.

Flight data remains a key tool in the pursuit of safety improvement within civil aviation, with an established procedure to extract, process and use the data in the context of FDM programmes, and the ongoing extension of its usage to other safety-relevant processes inside and outside operators. **The challenge remains to effectively implement FDM programmes by operators and to incentivize flight data usage beyond FDM**. As part of this Case Study, both the understanding of how operators implement FDM programmes and the identification of safety-relevant processes and industry-wide data exchange programmes that may benefit from the analysis of flight data will be key to the aforementioned objective of bridging between flight data sources and applications.

4.1.3 Stakeholders involved

As a requisite to a more complete understanding of FDM programmes and the general usage of flight data, the main stakeholders have been identified and their role described, be it as users, suppliers or regulators [63]:

- **Aircraft operators**: The main pillar of the FDM ecosystem, operators represent the organisations that generate flight data and are subject to the obligation of establishing an FDM programme (see section 4.2.1). They hold the deepest operational knowledge of all organizations and directly benefit from the improvements on flight safety resulting from the usage of flight data for FDM and other processes, while also incurring the costs.

- **Aircraft operator associations**: Within the context of flight data, operator associations serve to unify criteria, methodologies and other technical aspects of the usage of flight data from the operators' perspective. Their purpose is to aid, simplify and facilitate the establishment and maintenance of FDM programmes and other flight data uses through the sharing of knowledge among its members and as a collective representative when communicating with other stakeholders (mainly regulators and aircraft manufacturers.
- **Flight-crew associations**: Collective representation organisations tasked with the defence of flight crews' rights to data protection in any operation involving the handling of flight data [64]. Through their work ensuring that the FDM programme is non-punitive, as stated by the regulation (see section 4.2.1.2), flight-crew associations help pilot's maintain trust in the system and thus ensure the continuous flow of information needed to improve safety.
- **Flight-data-monitoring software vendors**: Suppliers of the software products used for decoding, processing and dashboarding of flight data as part of the FDM programme. Some vendors may offer FDM as a service, thus having access to the actual operational flight data. Their inputs are defined by the available sensors as determined by the aircraft manufacturer and the recorded format as determined by the FDAU/FDR/QAR manufacturer. Given this close connection, some of these stakeholders also act as software vendors.
- **Other software vendors**: Suppliers of the software products used for decoding, processing and fusion of flight data as part of other safety-relevant processes that may benefit from it (see section 4.1.2.). Subject to the same circumstances as FDM software vendors, the lack of an obligation for the usage of flight data within some of these other safety-relevant processes entails that the business case for their products is focused on both the safety and economic benefit of using the software.
- **Aircraft manufacturers**: Suppliers of the aeroplanes that generate the flight data, they define the sensor configuration within the aircraft and thus the data that will be generated by the operator and collected, recorded and stored by the FDAU/FDR/QAR integrated into their aircrafts. They benefit from operators' flight data usage through the detection of potential safety and performance improvements to their aircraft designs. They may also offer services equivalent to those of flight-data-monitoring software vendors.
- **FDAU/FDR/QAR manufacturers**: Suppliers of the specific hardware that collects, records and stores the flight data being generated by the aircraft sensors. Their products allow the direct selection of the format by which data will be recorded and later will have to be decoded. They may also offer services equivalent to those of flight-data-monitoring software vendors.
- **Research and educational institutions**: In the context of flight data usage, research and educational institutions serve as poles of expertise and innovation, where researchers can develop new technologies and capabilities and provide training and education on data analysis, risk management and other relevant topics. Additionally, research and educational institutions can collaborate with operators, regulators, and other stakeholders to conduct specific research activities on aviation safety through the usage of flight data, as well as form partnerships with technology companies to develop new solutions.
- **Regulators (national aviation authorities and international aviation regulators)**: Organisations tasked with the development and enforcement of regulations on the usage of flight data for FDM programmes and other safety-relevant uses. Issuers of the obligation to establish an FDM programme as a requirement to obtain and maintain the Air Operator's Certificate (AOC), they may also contribute to the definition, establishment and promotion of guidelines, acceptable means of compliance and standards to help operators comply with their obligations in an effective and efficient manner. In

addition, regulators may collaboratively analyse flight data in industry-wide data exchange programmes to identify industry-wide trends and patterns that could indicate potential safety issues.

The number of organisations involved, coupled with the regulatory flexibility on the specific implementation of FDM programmes (see section 4.2.1.2) has allowed the appearance of multiple methodologies, definitions and algorithms on the usage of flight data for both FDM programmes and other safety-relevant processes, which is one of the potential causes of the apparent lack of standards.

4.2 Overview of regulatory framework

Prior to the development of the actual Case Study, a review of the regulatory framework of Flight Data Monitoring programmes has been conducted in order to gain an understanding of the requirements established and guidance elements issued for compliance and adoption. In short, understanding the current regulatory framework will allow the assessment of:

- How digital capabilities are currently considered by the regulation and how future trends may impact its evolution.
- Which potential gaps within the regulation exist that could allow the regulator to influence over the development of digital capabilities (through regulatory, promotion, guidance or other means).

Documents examined include the main regulations in the context of EASA Member States (**Commission Regulation (EU) No 965/2012**), published Acceptable Means of Compliance (AMC) and Guidance Material (GM) from EASA, and other guidance and best-practices material from national CAAs, ICAO, the EAFDM and EOFDM forums, and other relevant industry stakeholders. Additional material has been reviewed to gain more visibility on the practical application of FDM programmes by institutional or private actors, including documents published by the FAA on the ASIAS programme and the proceedings of webinars and conferences.

Table 4-1 presents the exhaustive list of sources reviewed.

Table 4-1 Corpus reviewed for CS5

Case Study 5: Flight data models for safety			
Title	**Published by**	**Year**	**Reference**
Regulation and guidance			
Commission Regulation (EU) No 965/2012	OJEU	2012	[32]
Commission Regulation (EU) 2016/1199	OJEU	2016	[65]
Easy Access Rules for Commission Regulation (EU) No 965/2012 Air operations	EASA	2022	[14]
European Plan for Aviation Safety (EPAS) 2023-2025 Volume II	EASA	2023	[66]
Terms of Reference RMT.0392 Issue 1	EASA	2020	[44]
Temporary Guidance Leaflet No 44	JAA	2008	[67]
Title 14 of the Code of Federal Regulations – Aeronautics and Space (FAR)	-	2023	[68]
Annex 6 – Operation of Aircraft	ICAO	2008	[69]

Case Study 5: Flight data models for safety			
Title	**Published by**	**Year**	**Reference**
Evaluation of the relevance and the effectiveness of the EOFDM Best-Practices Documents	EASA	2021	[70]
Guidance for National Aviation Authorities on setting up a national FDM Forum	EAFDM	2017	[71]
Developing standardised FDM-based indicators	EAFDM	2016	[72]
Good Practice on the oversight of FDM programmes	EAFDM	2017	[73]
Review of Accident Precursors	EOFDM	2015	[74]
Guidance for the implementation of FDM precursors	EOFDM	2022	[62]
Flight Data Monitoring – Analysis Techniques and Principles	EOFDM	2021	[61]
Preparing a Memorandum of Understanding for an FDM Programme	EOFDM	2017	[75]
Key Performance Indicators for a Flight Data Monitoring Programme	EOFDM	2017	[57]
"Breaking the silos" - Fully integrating Flight Data Monitoring into the Safety Management System	EOFDM	2019	[60]
Doc 10000 Manual on Flight Data Analysis Programmes (FDAP) 2nd Edition	ICAO	2021	[58]
Flight Data Monitoring – CAP 739	UK CAA	2013	[76]
AC 120-82 – Flight Operational Quality Assurance	FAA	2004	[77]
Material Guía: FDM. Seguimiento de Datos de Vuelo	AESA	2022	[78]
Doc 9859 Safety Management Manual	ICAO	2018	[79]
Helicopter Flight Data Monitoring (HFDM) Recommended Practice for Oil and Gas Passenger Transport Operations	HeliOffshore	2020	[59]
Report 2012/01 Flight Data Monitoring Based Precursors Project Part 1 – Runway Excursions	UK CAA	2012	[80]
Other material			
OIG Audit of ASIAS – Report No. AV2021022	USDOT	2021	[83]
Annual Safety Review - 2022	EASA	2022	[84]

Case Study 5: Flight data models for safety			
Title	**Published by**	**Year**	**Reference**
Report on the Status of Aviation Safety Information Analysis and Sharing (ASIAS) Capability Acceleration	FAA	2020	[85]
Learning from All Operations: Expanding the Field of Vision to Improve Aviation Safety	FSF	2021	[86]
Unstabilised Approaches	DGAC (France)	2005	[87]
2021-2023 Most Wanted List – Install Crash-Resistant Recorders and Establish Flight Data Monitoring Programmes	NTSB	2021	[88]
Business Aviation Compliance With Manufacturer-Required Flight-Control Checks Before Takeoff	NBAA	2016	[89]
Acceptable Means of Compliance (AMC) and Alternative Means of Compliance (AltMoC)	EASA	-	[90]
European Authorities Coordination Group on Flight Data Monitoring (EAFDM) website	EASA	-	[91]
European Operators Flight Data Monitoring forum (EOFDM) website	EASA	-	[63]
Webinars			
Safety in Aviation Forum for Europe (SAFE) – FDM Event Proceedings	EASA	2022	[81]
MWL Roundtable: Safeguard Your Flights—Practical FDM Solutions for Smaller Operators	NTSB	2022	[82]

4.2.1 Regulation for EASA MS

The regulatory framework under which FDM programmes are operated is not equal around the world, with CAT aircraft operators under different jurisdictions bound to different sets of requirements. Here the topic is introduced through the ICAO Standards for FDM programme regulation, given their role within the aviation regulatory ecosystem. They are followed by the current regulatory framework for EASA Member States, in addition to the ongoing rulemaking tasks within EASA.

Even when the Scope of Work of this document is concerned with CAT aeroplane operators, regulation for offshore helicopter operations has also been included for illustrative purposes.

4.2.1.1 International Civil Aviation Organization (ICAO)

Internationally, ICAO standards advice ICAO Contracting States on the specifications or procedures whose uniform application is recognised as necessary for the safety or regularity of international air navigation. As such, its standards and recommendations serve as a blueprint that Contracting States may use when developing their own regulations. Annex 6 to the Chicago Convention contains the following on FDM programmes [69]:

‘Annex 6, Part I – International Commercial Air Transport - Aeroplanes

3.3.5 An operator of an aeroplane of a maximum certificated take-off mass in excess of 27 000 kg shall establish and maintain a flight data analysis programme as part of its safety management system.

Note. - An operator may contract the operation of a flight data analysis programme to another party while retaining overall responsibility for the maintenance of such a programme.

3.3.6 A flight data analysis programme shall be non-punitive and contain adequate safeguards to protect the source(s) of the data.’

‘Annex 6, Part III – International Operations - Helicopters

1.3.5 'Recommendation' - An operator of a helicopter of a certified take-off mass in excess of 7 000 kg or having a passenger seating configuration of more than 9 and fitted with a flight data recorder should establish and maintain a flight data analysis programme as part of its safety management system.

Note. - An operator may contract the operation of a flight data analysis programme to another party while retaining overall responsibility for the maintenance of such a programme.

1.3.6 A flight data analysis programme shall be non-punitive and contain adequate safeguards to protect the source(s) of the data’

4.2.1.2 European Aviation Safety Agency (EASA)

As of October 2012, **Annex III (Part-ORO) to Commission Regulation (EU) No 965/2012 (the Air Operations Regulation), point ORO.AOC.130** [32] contains, among the minimum conditions for an EASA Member-State-based aeroplane operator to obtain and maintain an air operator certificate (AOC), the requirement to establish a flight data monitoring (FDM) programme [62]:

a) *‘The operator shall establish and maintain a flight data monitoring system, which shall be integrated in its management system, for aeroplanes with a maximum certificated take-off mass of more than 27 000 kg.*

b) *The flight data monitoring system shall be non-punitive and contain adequate safeguards to protect the source(s) of the data.’*

Additionally, as of July 2016 [65], **Annex V (Part-SPA) to Commission Regulation (EU) No 965/2012, point SPA.HOFO.145** contains an equivalent requirement for operators seeking to perform helicopter offshore operations:

a) *‘When conducting CAT operations with a helicopter equipped with a flight data recorder, the operator shall establish and maintain a FDM system, as part of its integrated management system, by 1 January 2019.*

b) *The FDM system shall be non-punitive and contain adequate safeguards to protect the source(s) of the data.’*

Summarising the above articles, EU regulation mandates the establishment of an FDM programme in most airliner operators, with the cut-out value of MTOW 27 000 kg already covering multiple regional jets (e.g., Embraer 170, Bombardier Q400). The details of the FDM programme are not directly specified in the regulation but instead presented in the Acceptable Means of Compliance (AMC) and the official Guidance Material (GM) (see sections 4.2.2 and 4.2.3)

As part of its current rulemaking process, EASA plans to amend the Air Ops rules following feedback from the OPS standardisation inspections through RMT.0392 (i.e. Rulemaking Task), including changes at AMC and GM levels on flight data monitoring programme performance, to ensure minimum performance and effective support to the SMS [66] [44]. General changes may include better wording, additional guidance material, clarifications, solving omissions in the text, ensuring consistency of authority requirements with organisational requirements, and strengthening some GM by moving the text to AMC level or downgrading some AMC to a GM level.

4.2.2 Acceptable Means of Compliance for EASA MS

In the context of EASA Member States and given the high-level enunciation of the regulatory requirements, EASA has adapted previous material from the **Joint Aviation Authorities (JAA) Leaflet No 44** and has released multiple Executive Director (ED) Decisions throughout the years (**ED Decision 2012/017/R, ED Decision 2014/017/R, ED Decision 2021/005/R**), stating and updating the Acceptable Means of Compliance (AMC) to their regulation.

AMC are non-binding standards adopted by EASA to illustrate means to establish compliance with the Basic Regulation and its Implementing Rules, but they are not of a legislative nature. They cannot create additional obligations on the regulated persons, who may decide to show compliance with the applicable requirements using other means. However, as the legislator wanted such material to provide for legal certainty and to contribute to uniform implementation, it provided the AMC adopted by EASA with a presumption of compliance with the rules, so that it commits competent authorities to recognise regulated persons complying with EASA AMC as complying with the law [90].

The following list contains a summary of the key points covered by the current version of the AMC on FDM programmes **directly associated with flight data** (see AMC1 ORO.AOC.130 for a complete version [14]):

- The list of capabilities an FDM programme should enable for the operator, including the quantification of operational risks by highlighting occurrences through the usage of FDM information (frequency and level of severity of the event).
- The set of techniques that comprise FDM analysis, of which three are described: exceedance detection, all flights measurement, and statistics. It does not include any particular set of events to review or more technical specifications on how to execute these techniques, instead stating that "a set of core events should be selected to cover the main areas of interest to the operator".
- Regulatory requirements on FDR data take precedence over the FDM programme, particularly with regards to de-identification agreements between the operator and its crew.
- The set of requirements placed on the data recovery strategy, data retention strategy and the data access and security policy. These include the requirement to ensure a sufficiently representative capture of flight information to maintain an overview of operations and the requirement to retain a full dataset until the action and review processes are complete and thereafter a reduced dataset, with potential retention of samples of full-flight data. Satisfaction of both requirements necessitates of trained personnel and documentation to ensure retention of knowledge on how to maintain these capabilities.
- Which systems and equipment should be used to obtain FDM data, including a QAR and an FDR, the latter of which is highlighted as reducing the safety benefits obtainable due to the reduced set of data recorded.

Other key points covered by the AMC not directly associated with flight data include:

- Which are the responsibilities of the safety manager in the context of an FDM programme.
- Every crew member should be responsible for reporting events.
- The operator should pass on the lessons learnt to ensure safe aircraft operations to all relevant personnel and, where appropriate, industry.
- The data access and security policy, including the procedure to prevent disclosure of crew identity and which minimum definitions should this document contain.

4.2.3 Official Guidance Material and Best Practices for EASA MS

Below the level of AMC, EASA and other stakeholders release Guidance Material (GM) and Best Practices, which are explanatory and interpretation documents with a triple objective:

- Aid operators on meeting the requirements set in the regulation and the AMC regarding Flight Data Monitoring programmes.
- Facilitate the implementation of FDM programmes.
- Help operators draw the maximum safety benefits from an FDM programme.

Guidance Material and Best Practices are relevant to the regulatory framework of FDM programmes given the sharing of knowledge and ideas between the actual practice of Flight Data Monitoring by operators and the perception of the regulator on whether the target of improving safety is being fulfilled, which conditions the initiatives that EASA may launch in terms of rulemaking and safety promotion.

Given its non-binding nature, its in-depth content and its design as a practical tool, guidance material can originate in different jurisdictions and remain relevant worldwide. Nonetheless, operators will tend to benefit the most from guidance for practices under their jurisdiction, given the specificities contemplated and the aforementioned perception of the regulator. In the context of EASA Member States four main issuers of guidance exist:

- EASA, publisher of the official Guidance Material (GM) (see GM1 / GM2 / GM3 ORO.AOC.130 [14])
- National Aviation Authorities, which may produce guides and other material for their national operators (see [78] for an example).
- The European Authorities Coordination Group on Flight Data Monitoring (EAFDM) [91], an expert group of authorities dedicated to the promotion of FDM which publishes Institutional Best Practices for National Aviation Authorities (NAAs).
- The European Operators Flight Data Monitoring (EOFDM) forum [63], a voluntary partnership between European operators and EASA, publishing Industry Best Practices for operators.

Within the European context, additional guidance is published by the UK CAA [76] (until recently an EASA Member State) and HeliOffshore [59], a U.K.-based, safety-focused association representing the offshore helicopter industry.

Given the number and depth of guidance published, the following is a short summary of two documents released by the EOFDM forum, highlighted here due to their close linkage to the usage of flight data within the FDM programme:

EOFDM Working Group C – Flight Data Monitoring; Analysis techniques and principles

This document provides guidance on:

- How to identify and describe an operational risk.
- When is FDM relevant and reliable enough, and how to measure this reliability.
- How to define an FDM algorithm (the search window, the trigger logic, the severity).
- Where to find already defined FDM algorithms.
- How to test the FDM algorithm.
- How to produce meaningful statistics, which are the basic measures and methodologies.

EOFDM Working Group C – "Breaking the silos"; Fully integrating Flight Data Monitoring into the Safety Management System

This document provides guidance on:

- Data fusion and enriching FDM with other data sources
- Confidentiality requirements for FDM programmes and applicable legislation
- How to manage confidentiality
- How to use FDM for non-conventional use

Other significant best practice documents include '**EAFDM – Developing standardised FDM-based indicators**' and '**EOFDM Working Group B – Guidance for the Implementation of Flight Data Monitoring Precursors**', both concerned with the definition of FDM algorithms in a generalized manner. Given the divergence in parameters recorded on board between the different fleets, EOFDM guidance material aims 'to make use of parameters that are normally available in the mandatory flight recorder (FDR) so that the maximum number of operators can implement the monitoring of precursors described' [62].

These guidance and best practice documents, and in particular the latter, are in many cases the only available sources of information on the fundamental technicalities of implementing an FDM programme, including the definition of the algorithms required to capture different events. This fact is recognizable by the assignment of Safety Promotion Tasks to the EOFDM forum (see SPT.0126 in EPAS Vol II [66]) and by establishment of Member States Tasks to promote EOFDM good practice documents (see MST.0003 in EPAS Vol II [66]).

4.2.4 Regulation in other jurisdictions

Alternatives to the regulatory framework established in the ICAO standards do exist for any number of reasons, including historical, as national regulation may have been established before the topic was covered within the ICAO standards and these have not been transposed. Given their similarly sized aviation market, and the availability of public information, regulation for the United States of America (USA) is covered.

4.2.4.1 Federal Aviation Administration (FAA)

In the United States, the Federal Aviation Administration does not mandate the implementation of an FDM programme to air operators. Instead, regulation contained in **14 C.F.R. § 13.401** focuses on a scheme by which air operators voluntarily share de-identified data from their FAA-approved FDM programmes, in exchange of the FAA not taking enforcement actions against the air operator or its employees based on the data shared (except for criminal or deliberate acts). Approval and withdrawal of programme approval are also regulated by the same Section in the following manner [68]:

'(c) ***Requirements****. {…} The operator must submit, maintain, and adhere to a FOQA* (i.e., FDM) *Implementation and Operation Plan that is approved by the Administrator and which contains the following elements:*

(1) A description of the operator's plan for collecting and analysing flight recorded data from line operations on a routine basis, including identification of the data to be collected;

(2) Procedures for taking corrective action that analysis of the data indicates is necessary in the interest of safety;

(3) Procedures for providing the FAA with aggregate FOQA data;

(4) Procedures for informing the FAA as to any corrective action being undertaken pursuant to paragraph (c)(2) of this section.'

'(g) ***Withdrawal of programme approval****. The Administrator may withdraw approval of a previously approved FOQA programme for failure to comply with the requirements of this chapter. Grounds for withdrawal of approval may include, but are not limited to -*

(1) *Failure to implement corrective action that analysis of available FOQA data indicates is necessary in the interest of safety; or*

(2) *Failure to correct a continuing pattern of violations following notice by the agency; or also*

(3) *Wilful misconduct or wilful violation of the FAA regulations in this chapter.'*

In spite of the existing contrast between the approach to FDM regulation performed by EASA and the FAA, initiatives exist within the USA to modify the national regulation. The National Transportation Safety Board (NTSB), an independent federal agency charged with investigating every civil aviation accident in the United States of America, recurrently petitions the FAA to 'require a structured flight data monitoring programme that reviews all available data sources to identify deviations from established norms and procedures as well as other potential safety issues' [88].

The evolution of regulation observed both in EASA Member States and in the USA follows the conceptual evolution of FDM programmes from a voluntary safety improvement by a particular operator to a safety requirement for the whole aviation ecosystem, as the criticality of using flight data for safety purposes has been highlighted in the regional, national and global stage.

4.3 Digital capabilities and solutions

The previous section reviewed the regulatory framework governing Flight Data Monitoring programmes, which serve as the backbone of any other endeavour with flight data. At this point, the paper intends to focus on the set of digital capabilities and solutions that facilitate regulatory compliance, identifying a sample of the most relevant ones. The identified **key solutions have been grouped by categories, depending on the supplier of the solution:**

- **Industry-wide programmes** include all projects where data from multiple operators is aggregated and where the solution is managed and supplied usually by an institution using data from the programme members.
- **Commercial products** refer to commercially available digital solutions that perform most or all of the tasks required for an operator FDM programme as described in section 4.1.1 and are produced by a private corporation.
- **Papers / Scientific studies** describe research documents on topics related to Flight Data Monitoring or any of its subtasks, with a focus on the event definition, detection and analysis.

Moreover, the most relevant digital solutions have been analysed and their main features summarised with the aim of providing a detailed vision of the state-of-the-art digital solutions that can help operators to implement their FDM programmes and enable flight data for other safety-relevant processes.

The ultimate objective is to characterize the digital foundations that support the continuous operation of FDM programmes, serving as a basis for identifying potential development points or missing gaps in both regulations and digital capabilities, to be studied in greater detail throughout the project.

Table 4-2 Digital solutions programmes and research identified for CS5

Case Study 5: Flight data models for safety			
Programme Name / Paper Title	**Owner / Published by**	**Year**	**Reference**
Industry-wide programmes			
Data4Safety (D4S)	EASA	-	[92]
Aviation Safety Information Analysis and Sharing (ASIAS)	FAA	-	[93],[94]

Case Study 5: Flight data models for safety			
Programme Name / Paper Title	**Owner / Published by**	**Year**	**Reference**
Flight Data Exchange (FDX)	IATA	-	[95], [96], [97]
Papers / Scientific studies			
Using machine learning methods in airline flight data monitoring to generate new operational safety knowledge from existing data	J. Oehling & D. J. Barry	2019	[98]
Development of a Metric Concept that Differentiates Between Normal and Abnormal Operational Aviation Data	M. Stogsdill, D. Baranzini & P. Ulfvengren	2022	[99]
Optimized Flight Safety Event Detection in the National General Aviation Flight Information Database	A. P. LaBella, J. A. Karns, F. Akhbardeh, T. Desell, A. J. Walton, Z. Morgan, B. Wild & M. Dusenbury	2022	[100]
Recent Advances in Anomaly Detection Methods Applied to Aviation	L. Basora, X. Olive & T. Dubot	2019	[101]
An incremental clustering method for anomaly detection in flight data	W. Zhao, L. Li, S. Alam & Y. Wang	2021	[24]
Anomaly Detection in Aviation Data using Extreme Learning Machines	V. M. Janakiraman & D. Nielsen	2016	[25]
Hybrid Machine Learning–Statistical Method for Anomaly Detection in Flight Data	S. K. Jasra, G. Valentino, A. Muscat & R. Camilleri	2022	[27]
Flight Data Monitoring (FDM) Unknown Hazards detection during Approach Phase using Clustering Techniques and AutoEncoders	A. Fernández, D. Martínez, P. Hernández, S. Cristóbal, F. Schwaiger, J. M. Nuñez & J. M. Ruiz	2019	[102]
When Outcomes are not Enough: An Examination of Abductive and Deductive Logical Approaches to Risk Analysis in Aviation	M. Stogsdill	2022	[103]
Towards online prediction of safety-critical landing metrics in aviation using supervised machine learning	T. G. Puranik, N. Rodriguez & D. N. Mavris	2020	[104]
Sensitivity Analysis of Predictive Machine Learning Models to Aircraft Dynamics During Flare Maneuver	H. Lee, T. G. Puranik & D. N. Mavris	2022	[105]

4.3.1 Industry-wide programmes

As previously exposed in section 4.1.1, FDM programmes contribute to aviation safety due to their unique capability to identify and quantify operational risks over a database containing all flights flown by an operator.

The potential benefit of identifying FDM events, generating statistics that contextualize operations, and performing trend analysis to predict the appearance of risk factors, is compounded by the size of the database used.

As a logical development, a number of institutions have started industry-wide programmes to aggregate flight data from multiple operators and establish a collective quasi-FDM programme. They are not a substitute of an airline FDM programme, as they do not relieve an EU-based operator from complying with ORO.AOC.130 requirements shown in section 4.2.1.2.

These industry-wide programmes are characterized by the focus on data protection and de-identification, by their voluntary participation, and the sponsorship of an institution, all three factors closely linked. Given the sensitivity of flight data (for data protection, legal reasons, and potential responsibility for safety violations to their oversight authorities), operators limit the sharing of data. In order to make the exchange of data a reality, institutions have had to act as intermediaries, trusted “data brokers” capable of guaranteeing to operators the protection of their data (de-identification) while providing them with an incentive to join and voluntarily participate in the programme through the development of new FDM capabilities.

Currently three big data-sharing programmes are on-going:

- **Data4Safety (D4S) programme - EASA:** Data collection and analysis programme that will support the goal to ensure the highest common level of safety and environmental protection for the European aviation system [92]. The programme allows to better identify where risks are (safety issue identification), determine the nature of these risks (risk assessment) and verify if the safety actions are delivering the needed level of safety (performance measurement). The programme aims at collecting and gathering all data that may support the management of safety risks at European level, first and foremost flight data from European operators, but also including safety reports (or occurrences), surveillance data (air traffic data), weather data, etc. The main highlights of the programme include:
    - Led by EASA, co-funded by Directorate-General for Mobility and Transport (DG MOVE), participants include aviation OEMs, European airlines, NAAs and other aviation stakeholders (e.g., pilot associations).
    - Collaborative Analysis platform and Big Data platform where experts from the Member States and the industry can work together with data scientists.
    - Outputs for both the individual organizations involved and the wider European Aviation System, including metrics, directed studies on particular safety topics, blind benchmarking capabilities for operators (i.e., direct safety performance comparison with the industry) and vulnerability discovery.
    - Data Governance document developed collaboratively by Programme Members. Member airlines can identify their own flights. Applies “Rule of 3” (any subset of data for which SPIs are shared must contain operations from at least 3 airlines).
    - Big Data platform and data storage and protection managed by a dedicated third-party organisation, Data Analytics capabilities provided by programme Member experts and a dedicated third-party organisation.
- **Aviation Safety Information Analysis and Sharing (ASIAS) programme - FAA:** Safety analysis and data sharing collaboration programme to proactively analyse broad and extensive data to advance aviation safety [93]. ASIAS fuses various aviation data sources in order to proactively identify safety trends and to assess the impact of changes in the aviation operating environment. The two components of this activity are the analysis of aggregate data and the sharing of information in support of Safety Management Systems. The programme utilizes publicly available data (e.g., air traffic management data related to traffic, weather, and procedures), as well as non-public data (e.g., ATC data, flight data from operators, safety reports, manufacturer data) [83]. The main highlights of the programme include:

    - Led by the FAA, participants include aviation OEMs, US airlines, general aviation operators, industry associations, MRO centres, flight training centres and other governmental agencies.
    - Issue Analysis Teams composed of members which execute activities directed by the ASIAS Executive Board, and which develops proposals and priorities and process changes for the programme [85].
    - Outputs for the aviation community and government, including metrics, quick-look studies (i.e., initial investigations on emerging safety issues), directed studies on particular safety topics, blind benchmarking capabilities for operators, and vulnerability discovery.
    - Data Governance document developed collaboratively by Programme Members.
    - Big Data platform and data storage and protection managed by a dedicated third-party organisation, Data Analytics capabilities provided by the FAA, programme Member experts and a dedicated third-party organisation [94].
- **Flight Data Exchange (FDX) Programme - IATA:** Aggregated de-identified database of FDM events from voluntary participant airlines [95]. Allows for comparison of standard safety performance metrics (SPI) through benchmarking of own performance against other operators with similar aircraft types and/or geographical regions. The programme utilizes airline flight data, with only a sample of flights processed, broad thresholds to accommodate all types of operations, and strict de-identification.
    - Led by the IATA, participants include member airlines from all over the world.
    - Though not its principal purpose, IATA may partner with airlines to provide in-depth analyses when required.
    - Outputs for programme members, including metrics and blind benchmarking capabilities for operators.
    - Strict de-identification protocol, original flight data file is deleted once a new binary is generated without identifying information. Applies "Rule of Three" (see Data4Safety programme) [96]
    - Big Data platform and data storage and protection managed by a dedicated third-party organisation, Data Analytics capabilities provided by IATA and a dedicated third-party organisation [97].

While D4S and ASIAS are similar programmes in scope and objectives, each addressing the safety needs of the European / US aviation environment, FDX offers a smaller number of outputs but to a wider, global audience of aircraft operators. As industry-wide programmes they allow many operators to compare their SPIs and other measurements to one another in different contexts, providing unique capabilities to safety management.

Their value, however, resides in their role as accelerators of the usage of flight data for other safety purposes beyond Flight Data Monitoring programmes. The industry-wide programme collaborative framework, under the adequate governance structure, is great platform to explore innovative uses for flight data given the efficiency in costs, effort, availability of data and expertise that result from the pooling together of resources by the industry. They also serve as a platform to incentivize and establish common standards and procedures, resulting from the collaborative approach to tasks within the programme (e.g., directed studies on airworthiness). Nonetheless, challenges do exist, chiefly among which the decoding of data due to the lack of standardization of data format and performance among operators and fleets, compounded by the difficulty some operators have to obtain and maintain the knowledge to decode their flight data into usable values.

4.3.2 Commercial products

The objectives of a Flight Data Monitoring programme include the assessment of safety risks through the identification of areas of operational risk, the quantification of these risks by identifying occurrences of unusual/unsafe circumstances (recording their frequency and severity), and the determination of when an operational risk becomes unacceptable based on the trends of occurrences observed.

While regulation in EASA Member States affirms the ultimate responsibility of the operator over the programme (see section 4.2.1.2), it does not prohibit the airline from using external tools or services. As such, and given the technical complexity of analysing big sets of data, a significant number of commercial products have appeared in the last decades. These products are designed to perform a substantial amount of the tasks that conform the FDM process, from the decoding of flight data using the Logical Frame Layout (LFL) provided by the operator, to the computation of events and measurements and the display of results in the form of dashboards and time series. Event algorithms are usually pre-defined and can be refined by the operator modifying the logic or the thresholds.

While their basic capabilities are relatively similar, some include additional features. These range from 3D flight animations to Primary Flight Display (PFD) animations, fusion of additional data sources such as weather data, fatigue scores and flight plans, some benchmarking capabilities or the automatic transfer of data from the aircraft to the FDM software through wireless or network.

Products may be designed for broad categories of operators (e.g. accept any fixed wing and rotary wing aircraft) or for smaller groups (e.g. business jets), with distribution also being flexible, ranging from the outright purchase of a license for the operator to use the software in-house (be it through a local software copy or as Software as a Service (SaaS) web-based platform), or the outsourcing of the whole service, where the service provider is responsible from decoding to the preliminary event analysis.

Ultimately, the initial conceptualisation of the FDM programme as a siloed task within the operator, only interacting with its SMS process, has meant that most commercial products are very much tailored solutions to the regulatory requirements on operators, as their incentive is to be easily integrated and accomplish the exact tasks required. At the current stage, however, the differing maturities of FDM programmes among operators, and the products designed to address their needs at each maturity level, entails a lack of standardization in the definition of the most basic elements (e.g., parameters, event algorithms, thresholds). It has also led to limitations within operators to retain knowledge on the data and the algorithms, as these products already include pre-defined metrics and algorithms to facilitate the work of the operator, but ultimately limits their capacity to benefit from their FDM programmes and to use their flight data for other safety and non-safety relevant purposes, including their participation in industry-wide programmes.

4.3.3 Research

This section presents an overview of the direction that scientific and academic studies are following in the fields of FDM and flight data usage for safety. The ultimate objective is to characterize the new digital capabilities that are currently being developed and which may impact on the spectrum of solutions already identified, both commercial products and industry-wide programmes. These capabilities are relevant in so far as their adoption can impact future regulation and guidance on FDM programmes in particular and on the usage of flight data more broadly.

The state-of-the-art approach to FDM event generation, consisting of exceedance detection algorithms with pre-determined threshold values set by subject matter experts presents two major drawbacks [98]:

- Thresholds can be incorrectly set, and may be detected when too many events are generated (false-positive) or too few (false-negatives), the latter of which may be difficult to detect. This problem is particularly acute for new operators, as guidance generally specifies the requirement for the operator to adapt thresholds to their own SOPs and needs, but these may be complex to specify and translate into an exact threshold value.

- Events, by definition, can only be generated for occurrences for which an algorithm has been defined. If the operator decides to omit a particular algorithm, or if the algorithm does not exist as the occurrence has not been imagined yet, there will be no event.

To address both these points, **research has focused on improving the definition of events and the detection of unsafe events without a related taxonomy (anomalies). For the latter, the usage of Machine Learning (ML) tools is widespread.** The previous two topics of research, however, address the analysis of past data and the production of retrospective insights on safety for which corrective measures are applied for future flights**. These provide limited value real-time risk identification or decision-making** [104]**, in response to which scholars have focused on the real-time prediction of occurrences and flight data.**

Within the topic of the **improvement on the definition of events**, some studies [100] have focused on the refinement of currently existing event algorithms or the definition of new algorithms that can be used to contextualize events. These refinements may entail the adaptation of events for particular casuistries, such as General Aviation (GA) flights, that improves detection rates for true-positives and decreases false-negatives, while other refinements focus on improvements in terms of processing speed and power. Another topic under research [99] is the construction of complex artificial variables from the combination of flight parameters which can, by themselves, trigger an event. These variables are characterised by not being restricted in terms of simultaneity, such that temporal factors can be considered on an aggregate level.

Closely related, research on the **detection of unsafe events without a related taxonomy** consists generally of the usage of Machine Learning (ML) algorithm to detect anomalies in flight data. The current focus on Machine Learning, and particularly in its most recent advances, is driven by its capacity to scale well with large datasets and with high-dimensional data in comparison to classical statistical and machine learning techniques [101]. In this line, scholars [24] have used Gaussian Mixture Model (GMM) algorithms coupled with an expectation-maximization (EM) algorithm to significantly reduce processing time and memory usage in comparison with traditional clustering models, allowing faster processing of flight data. Others have used Extreme Learning Machine (ELM) [25], Local Outlier Factor (LOF) algorithms [27], or Artificial Neural Networks (ANNs) using an AutoEncoder architecture [102], to discover operationally significant anomalies in large aviation data sets.

Real-time prediction of events based on flight data analysis may well be the future of flight data monitoring and of aviation safety. Stogsdill [103] argues that the underlying logic governing the traditional (and current) approaches to assess safety and risk within aviation (and other safety critical systems) is abductive and therefore focused on creating explanations rather than predictions. The scholar proposes an alternative approach that adds temporality to the concepts of safety and risk, thus allowing for a deductive analysis approach and the creation of predictions not bound to analysing past outcomes. Others [105] have also explored the concept of real-time prediction through the analysis of the sensitivity of Machine Learning models to the impact of ground effects and pilot behaviour during the flare manoeuvre, where flight parameters are difficult to predict. Such predictions have also been performed using Random Forest (RF) regression algorithms live during the approach phase, with positive results [104].

While many of these research topics may have a positive impact on aviation safety, their operationalization will depend, in part, on the existence of new standards or mechanisms that provide adequate confidence in the functioning of AI/ML applications when demonstrating compliance with requirements. As explained in 3.3.4, elements such as the integrity of the results of the algorithms, based on their criticality, traceability and ethics in their training are key components to be managed in the future, with EASA already taking a holistic approach to the issue by means of **EASA's Artificial Intelligence (AI) Roadmap** [56].

4.4 Conclusions

Flight data, as has been explained throughout this chapter, is a key component of aviation safety. While usually connected to FDM programmes, its use can be extended to other safety-relevant processes, many of which may be performed outside the scope of the operator that generated the flight data. The incentive to the operator to share their data remains a challenge, as the regulatory framework overview showed that legal requirements are limited to the establishment of an FDM programme, and that there exist legal and data protection restrictions to sharing the data.

Industry-wide programmes represent a solution to this problem. The pooling of resources, data and expertise allows operators, regulators and other parties to innovate in the usage of flight data for safety at a scale not possible within their siloed FDM programmes.

These industry-wide programmes, however, also face their own set of challenges, some of which are specific to these programmes, while others are inherited challenges that operators already face. In particular, the main limitations and constraints include:

- **Lack of standards regarding flight data format:** EU rules for air operations in the AMC to Part-CAT define the minimum list of flight parameters required for Flight Data Recorders (FDR), which set the baseline for any FDM programme. Nonetheless, the standards regarding flight data format are not fully consolidated. Significantly missing is the minimum set of flight data and their minimum performance (e.g., accuracy, sampling rate) for supporting effectively FDM programmes and safety-relevant processes. This challenge represents a friction point to the usage of flight data outside FDM programmes, as their historical association conditions the format in which flight data is recorded and stored, a format that may be inadequate for other uses and users.
- **Challenges at adjusting the collected flight data for safety needs:** Validation of collected flight data is a labour-intensive task that entails continuous monitoring, refinement and analysis of flight sensor data as well as the metrics and pseudocodes implemented. Validation requires both expertise on the flight data (data model, decoding process, data quality and issues) and flight operations (specific operational boundaries of the operator). Often, not all knowledge is held by the operators, but distributed between the FDM service provider, the internal FDM team, safety experts and flight operations. Without the right coordination mechanisms, effective validation of flight data to meet the safety needs is a challenge.
- **Challenge at defining a flight data access & security policy:** The vast majority of FDM software packages on the market permit the establishment of certain function-based access levels to regulate data access, which enables limiting personally identifying information to designated individuals while maintaining the effectiveness of the FDM team's analysis work. However, there are no practical guidance or standards to define function-based access rules to FDM data. This topic is further complicated by the usage of flight data outside the boundaries of an FDM programme, as additional personnel inside and outside the operator gain access to the data.
- **Challenge at obtaining and maintaining the knowledge to decode collected flight data into usable values:** As a practical method of setting up a fully operating FDM programme, more and more operators choose to outsource FDM tasks. The benefits include the possibility of swiftly establishing such an FDM programme without the need to find qualified individuals in the field of flight data and acquire corresponding equipment and systems. However, this also makes it difficult for operators to keep that knowledge within the organization, which is important for the establishment of FDM algorithms that are relevant and adjusted to their operational specificities, for the correct interpretation of FDM results, and for the usage of flight data within other safety-relevant processes that the outsourcing service does not provide. At the same time, it becomes a limit for the participation in industry-wide programmes and forums.

5. Conclusions

While the literature review and digital capabilities and solutions identification presented in this document has been developed separately for each case study, common challenges exist in the form of a lack of guidance material and standards on a number of different topics:

- **Standardised data**: Some of the most important data sources within the aviation safety ecosystem are not standardised across operators. These include flight data used in FDM programmes, training data from EBT programmes or statistical data on aircraft-route combinations that the regulation requires to implement the Basic Fuel Scheme with Variations or the Individual Fuel Scheme. Either through guidance or regulation, standards are required if the usage of such data is to be simplified and for the potential benefits of data sharing through industry-wide programmes (such as the Data4Safety) are to be realized to the fullest.
- **Data fusion guidance and usage in other areas:** With many capabilities being unlocked or enhanced through the usage of data from external sources (e.g., FDM data in EBT programme definition and scenario contextualization, operational and traffic data for fuel management), strategies to integrate these data sources must be defined. Progress has already been made in the fusion of some sources, particularly to flight data, but guidance is scarce for EBT programmes and fuel management.
- **Data governance and knowledge management**: The organizational, data governance and knowledge management dimensions are key for the effective protection and safety of the data and its integration with processes at the operator and data-sharing programme levels. While some level of guidance exists on data protection for FDM and EBT programmes, it is missing on the overall topic of governance and knowledge management.
- **New advanced analytics**: Machine Learning solutions are being introduced into many processes and tools of the three case studies. While their capabilities in terms of data analysis, pattern recognition and future prediction can be positively disruptive, the adoption of these state-of-the-art solutions may require new technical standards and guidance in order to ensure the integrity of the data, procedures and results, the adaptation of these capabilities to the needs and safety requirements of the aviation sector and the presence of appropriate skills among aviation professionals to use and produce meaningful and relevant results with ML techniques. EASA has already taken a holistic approach to the issue by means of EASA's Artificial Intelligence (AI) Roadmap, but specific guidance is still missing.

These challenges together with those identified particularly for each case study draw the direction of the analysis to be done in the next steps. The case studies development will address the benefits, constraints, standardisation and deployment issues already identified at this stage of the project to be able to provide recommendations for adjusting safety regulations and related standards.

6. Next steps

The main objective of this project is to identify and assess relevant changes to existing aviation safety standards in order to support the deployment of new digital solutions. Through the review of existing literature and the identification of digital solutions, this document presents the background and context in which the case studies under the scope of the project will be developed. The regulatory framework together with the identified digital capabilities will allow the definition of the work plan to be followed during the case study development and stakeholder consultation in the next phases of the project.

The challenges identified during the desk research, whose results are presented in this document and summarised under the conclusions, already give an indication of the scope and detailed objectives of each case study. An individual work plan will be designed for each case study, aimed at defining the guidelines of the tasks to be undertaken, covering:

- Refinement of the detailed objectives of the development phase for each case study based on the analysis performed in this document and in accordance with EASA.
- Definition of the areas and processes that might be impacted in each case study based on the detailed objectives, further specifying the digital capabilities and solutions upon which the next phase of the case study will be developed, and which stakeholders will be impacted.
- Methodology to collect data, including the relevant stakeholders and which methods are most adequate and for which subset of stakeholders (e.g., interviews, brainstorming sessions, questionnaires).
- Design of the case study performance plan in detail, with all steps of the analysis following the benefits of the EBT/CBTA concepts, digital fuel management and FDM programmes already identified, the expected output for each step, the main risks associated and proposed mitigations.
- Develop use cases for the assessment of the impact of the identified digital capabilities and solutions. Particularly for the impact assessment:
    - Methodology to define what is understood as "existing operations" within the industry beyond what was analysed in this document, which may require collecting data and/or conducting interviews with operators and/or other industry stakeholders.
    - Methodology to evaluate how the new digital solutions would impact the "existing operations" through a technical assessment of the identified solutions. It may also require collecting data with operators, solution owners and/or other industry stakeholders.
    - Methodology to evaluate the key benefits and limitations of each digital solution, including how relevant stakeholders will be identified and benefits/limitations assessed qualitatively and, when feasible, quantitatively.
    - Methodology to assess the maturity level of each digital solution analysed through the definition of a maturity level categorisation system, including the criteria and maturity levels used.
    - Methodology to identify "remaining uncertainties" and which areas are to be considered (e.g., operational uncertainties, legal uncertainties, etc.) based on the maturity level assessment.

Understanding the details of the EBT/CBTA concepts, the state-of the art of the digital fuel management and also the flight data models for safety has allowed identifying the key stakeholders to be involved in the consultation process supporting the case study development. Table 6-1 below presents the preliminary list of targeted stakeholders, which will be refined as part of the work plan definition in the next phase of the project.

A contact list will be elaborated in collaboration with EASA to achieve stakeholder involvement in the project through interviews, questionnaire answering and workshop participation. The expected contribution from the stakeholders targeted for consultation will be established as part of the work plan definition.

Table 6-1 Targeted stakeholders for consultation process

Stakeholder	Role and potential interest in the project		
	Case Study 3	Case Study 4	Case Study 5
Airspace Users	Direct users of the EBT/CBTA programme. They can gradually move from a traditional task-based system towards a new competency-based training system, accomplishing the requirements set in the applicable regulation. Within AUs, the main affected departments are: • Flight crew is the main focus of the EBT programmes defined according to the competency-based training and assessment principles. Pilot belonging to airlines (commercial air transport – CAT) are currently included in the scope of the regulation, but future developments aim to include other types of aircraft like helicopters. • Instructors and examiners have a key role in the application of the competency-based assessment and using the defined grading system to evaluate the pilot competencies.	Direct users of digital fuel management aiming to optimise fuel consumption and aircraft efficiency. The main affected departments are flight crews, dispatch, performance department, navigation and operations control.	Direct users of safety risk management and SMS certificate holders, as the main area benefitted by FDM programme. Within AUs, the main affected department are: • Maintenance, Repair and Overhaul (MRO) Centre as flight data can be used for critical maintenance identification. • Safety department as FDM supports the core processes through the identification, quantification and the assessment of operational risks.
Original Equipment Manufacturers (OEM) – aircraft and FDAU/ FDR/ QAR			Design products better adapted to the needs of their clients based on their operational performance and the environmental conditions they most encounter, overall improving safety.
National Aviation Authorities	Assess and approve the implementation of EBT programme by airspace users following EASA's regulation and guidance.	Approve the individual fuel schemes and required to have qualified personnel with the necessary knowledge and expertise to understand, monitor, and validate the	Responsible for approval of FDM programme implementation under Air Operator Certificate (AOC) and also involved in the normalisation of FDM events.

Stakeholder	Role and potential interest in the project		
	Case Study 3	**Case Study 4**	**Case Study 5**
		criteria of the fuel management rules.	
European Aviation Authorities	Able to use the results of the project as input for the development of new regulations and impact on the existing ones by making use of the aspects identified during the project for each Case Study.		
Digital solution providers	Answer to the identified needs and offer tools to help stakeholders design and implement data related programmes under the scope of the project.		
International organisations	European Cockpit Association (ECA). International Federation of Air Line Pilots' Associations (IFALPA).	European Cockpit Association (ECA).	Flight Safety Foundation (FSF).
	International Air Transport Association (IATA).		

After developing the case studies, results will be shared with stakeholders in order to validate the development of use cases and collect feedback and recommendations. This most suitable dissemination channel will be agreed with EASA depending on the message to be sent and the targeted audience.

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