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Digital Transformation in Aeronautics through the ICARUS Aviation Data and Intelligence Marketplace

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Abstract. Today, digital transformation has drifted all industries with its proven capacity to improve operations and boost revenues while building a value chain ecosystem. The aeronautics ecosystem is almost unanimously invested in some way into a digital transformation strategy in which data typically plays an instrumental role. However, despite the vast quantity of data across myriad parameters that never stop flowing across the aircraft-passengers-luggage-cargo journeys, the aviation-related stakeholders are still at a relative disadvantage in terms of data gathering and sharing, especially since the eternal questions of "who owns the aircraft" and "who owns the passenger" remain open. In this contact, the present paper focuses on the design and delivery of the ICARUS data and intelligence platform that aims to enable trusted and fair data sharing and insightful data analytics in an end-to-end secure manner. The methodology followed during the implementation of the ICARUS platform is defined, the aviation data value chain is elaborated, the ICARUS Minimum Viable Product is outlined and the theoretical foundations of the ICARUS data management and value enrichment methods are introduced, giving way to a brief reference to the ICARUS unique selling points and platform implementation.

1 Introduction

Over the past years, the digital transformation wave has aspired to generate 'connected' aircraft and passenger experiences in aviation. Despite its technological sovereignty, the aviation ecosystem from airlines and airports to OEMs and MRO providers is in fact not resting on its laurels, but is almost unanimously invested in some way into a digital transformation strategy, with 58% of airlines and 35% of airports already having a strategy in place [1].

At the same time, data is nowadays at the heart of the disruptions occurring across the economy, with aeronautics stakeholders aggressively investing in harnessing their data as critical corporate assets to drive strategic insights, improve operations, and support faster

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aircraft turnaround and predictive maintenance timings [2]. Over the past years, various ambitious initiatives to mine and exchange data within closed ecosystems of aviation stakeholders at the same level have emerged (e.g. GADM by IATA mainly intended for use between airlines, SKYbrary by EUROCONTROL between Air Traffic Control authorities and airlines, A-CDM between airports, and Skywise between Airbus and airlines) yet there is still little data diffusion and sharing across the plethora of the broader aerospace-related stakeholders. Although the aviation industry is one of the earliest adopters of data science, the aviation ecosystem as a whole though is still not able to effectively manage and process the underlying multi-party "data deluge" and "data exhaust" and get access to the right data at the right time in order to evolve towards and beyond the 3rd generation Artificial Intelligence, namely Analytical Awareness, according to a recent IATA report on AI in Aviation [3].

In this context, the present paper will focus on the ICARUS platform that leverages aviation data to help companies and organisations (whose operations are directly or indirectly linked to aviation) to simultaneously enhance their data reach, as well as to share / trade / enrich their existing data sources and intelligence, in order to gain better insights into their status quo. From its conceptualization phase, the ICARUS project has identified a strong market need for: (I) trusted and fair data sharing, (II) affordable and cost-efficient data linking and (III) insightful and understandable data analytics, in the aviation data value chain, in alignment with the recommendations of a number of policy and industry-specific initiatives. To this end, in support of the Industry 4.0-inspired quest for data-driven digital transformation, ICARUS offers a set of unique offerings to 1st-tier (e.g. airports, airlines, aircraft manufacturers, etc.) and 2nd-tier (e.g. OEM suppliers, MRO providers, GDS providers, etc.) aviation stakeholders.

2 Methodology

In order to develop a platform that effectively addresses the aviation industry needs and requirements, a 4-step methodology has been iteratively applied as follows:

- <u>Phase I: Analyzing the Aviation Market Needs</u>, when the needs and requirements of the market and, in particular, of the aviation industry, are elicited. Market research in ICARUS has followed four parallel streams: (a) State-of-play analysis that reviews and compares existing products and tools related to the ICARUS technology stack, (b) Aviation industry needs identification that focuses on discovering the needs and requirements of the potential clients of the ICARUS outcomes, through interviews with key stakeholders and online questionnaires to ensure the generalisation of the requirements for the whole aeronautics industry; (c) Business scenarios and requirements consolidation through focus groups with stakeholders; (d) Aviation data in-depth exploration for collecting representative (open and private) data, and understanding the repercussions of the emerging stakeholders' needs for data protection, IPR and brokerage.
- <u>Phase II: Developing the ICARUS Platform</u>, that includes the methodology conceptualisation, the technical requirements extraction, the architectural design, the actual development, and the integration of the ICARUS multi-sided platform.
- <u>Phase III: Verifying, Validating and Demonstrating the ICARUS Platform</u> according to an all-inclusive framework (from the conception to final release and experimentation in pilot settings). The ICARUS platform and the data services bundles it offers need to be built in the right way, without bugs, malfunctions and security issues (verification), and to be appropriate for the needs of the targeted stakeholders (validation). To this end, an iterative approach, engaging the project's pilots, namely [Demonstrator I] Airport capacity planning; [Demonstrator II]

Enhanced routes analysis of aircraft for improved fuel consumption optimisation and pollution awareness; [Demonstrator III] Improved modelling of infectious disease spreading based on aviation's passenger data; and [Demonstrator IV] Enhancing inflight experience, in the assessment and feedback loop from the very early development stages, is envisioned in ICARUS.

- Phase IV: Preparing Market Entry, with the purpose of preparing a successful entry in the market, by constantly analysing the market, and by devising a detailed exploitation and stakeholder engagement strategy.

3 Aviation Data Value Chain

Looking at the different stakeholders who can offer or are in need of aviation-related data, a novel data value chain is intuitively created bringing together the aerospace, tourism, health, security, transport, retail, weather, and public sectors. With the aviation value chain being characterised by a high degree of vertical disintegration, the diverse stakeholders whose data-driven collaboration needs to be accelerated are classified into three core tiers as depicted in Figure 1:

- Data Tier 1: Primary Aviation Data consists of aircraft sensor data, scheduled route plans, airport traffic, fuel emissions, passenger data that pile up in heaps of data in every flight. Typical data providers include airports, airlines, and aircraft manufacturers.
- Data Tier 2: Extra-Aviation Data features data collected by airport services providers, and aviation-related service providers. Such data concern passengers' profiles which are complemented by Linked Open Data (indicatively weather, environment) and other historical data.
- Data Tier 3: Aviation-derived & Aviation-combined Data contains data and knowledge from other sectors (like Health, Tourism, Public Sector) that can be combined with aviation data from tiers 1 and 2 to produce new derived data and create new knowledge that would be impossible to deduce otherwise.

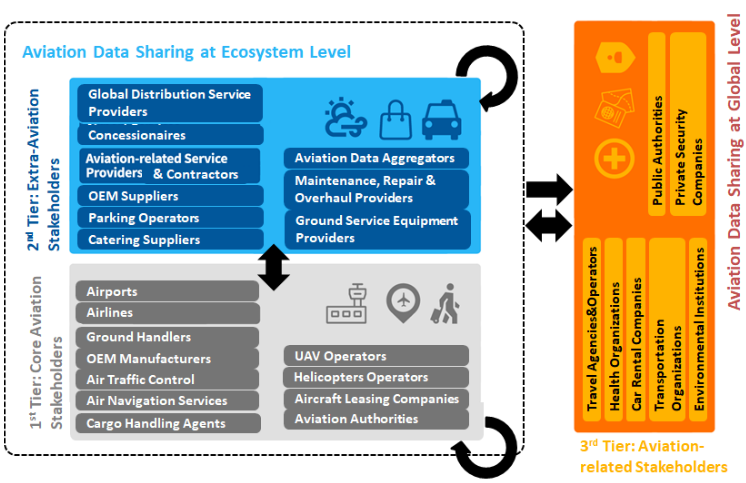
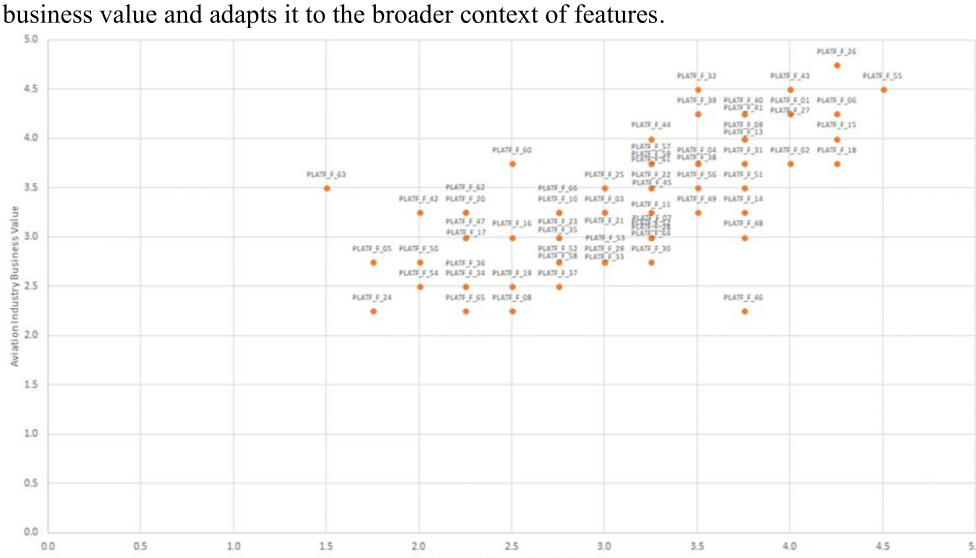


Fig. 1. Aviation Data Value Chain.

Taking into account the different roles and the interactions anticipated in the Industrial Data Space [4], as well as the additional roles, such as data publisher, data facilitator, data broker and data curator, that are often encountered in the bibliography [5], our approach has conceded for simplicity reasons to adopt only the core roles of: Data Provider (responsible for generating and maintaining data) and Data Consumer (accessing, using, and running analytics on data acquired from their rightful data providers).

4 ICARUS Minimum Viable Product (MVP)

In preparation of the design and development phases of the project, the ICARUS Minimum Viable Product (MVP) has been defined in order to ensure that the ICARUS platform is designed and viewed as a product with enough features to satisfy early customers, minimizing the risk of failure and improving the value generated. The MVP is directly linked with the lean start-up approach in the design and development and bears three core phases, namely Feature Definition, Feature (Internal and External) Assessment and MVP Consolidation. In the 2 MVP iterations, 71 features were extracted and elaborated, and assessed at different levels by representative stakeholders of the 3 data tiers (ranging from airports, airlines and aircraft manufacturers, to aviation data companies, health organizations, research institutes and aviation software companies). As depicted in Figure 2, the relevant stakeholders were requested to describe and rate online in a qualitative manner: (a) the anticipated business value of each feature for their own organization and (b) the expected business value of each feature for the overall aviation industry, using a scale between 1 (Little or no impact on internal operations, Little or no competitive advantage for ICARUS in the aviation industry) and 5 (Extreme impact on internal operations, Critical competitive advantage for ICARUS in the aviation industry) points and taking into account their respective responses to the questions: (a) How important is this feature for your internal operations? (b) How crucial is this feature for the broader aviation industry? The scale that has been adopted builds on international practices regarding the assessment of the business value and adapts it to the broader context of features.



PLATF_F_67	Encryption and decryption of data in an end-to-end manner	Depending on the data provider's preferences, the data assets can be always stored and exchanged in an encrypted form. The ICARUS platform does not store any decryption keys but they are directly exchanged among the involved parties: data provider and data consumer on-premise clients, or data provider on-premise client and data consumer's secure and private space.

PLATF_F_62	"Closure" of a data contract, proceeding to the analysis or to download a specific data asset	A data contract is considered as active only when the payment is confirmed by the data provider and written on the blockchain. Once this happens, a data consumer gets access to a data asset.

Fig. 2. ICARUS MVP Feature Assessment and Indicative Features.

5 ICARUS Data-driven Methods at a Glance

The ICARUS platform essentially builds on a bundle of data management and data value enrichment methods that have been defined taking into account the aviation industry needs, requirements and peculiarities while building on an extensive state-of-the art analysis and creating a compelling case for the aviation data value chain, vis-a-vis certain key considerations and open challenges. In brief, the ICARUS data management and data value enrichment methods span over the following axes:

- <u>Axis I: Data Collection</u>, that considers the upstream (direct data discovery and gathering from their rightful source), downstream (aggregation and distribution of data through an intermediary which typically acts as a data broker), indirect (derivative data and intelligence as emerging from an analysis performed) and open data assets' collection from the supply-driven perspective of the data providers. The de facto data collection approach in ICARUS concerns files upload / exchange while the applicable processes for data check in and data update have been elaborated and the supported data profiles in terms of formats and standards have been put into context.
- <u>Axis III: Data Curation</u>, involving the data cleaning, data provenance and data mapping and linking perspectives to be applied in ICARUS. In particular:
    - The *ICARUS data cleaning process* aims at increasing the data quality by detecting and correcting (or removing) corrupt or inaccurate records, through its 5-step process, namely Preliminary Data analysis, Definition of the validation rules, Definition of the cleansing workflow with the cleansing and missing value handling rules, Cleansing workflow execution, and Verification.
    - The *ICARUS data provenance process* practically captures and manages trustworthy data asset trails that shall effectively track the lineage and the derivation of the data assets that have been checked in in ICARUS in a coarse-grained, light-weight manner at dataset level, considering the agent, artefact, process and timing perspectives.
    - The 8 phases of the *ICARUS data mapping and linking approach* (ranging from Modelling, Model Storage, Mapping Algorithms Definition and Training, and Model Evolution, to Semi-automated Data Mapping, Data Transformation and Data Linking) ensure effective data integration at data check-in time and at data query time and concur in creating compatible data assets at syntactic and semantic level based on the ICARUS common aviation data model. The emphasis laid by ICARUS on the data model lifecycle and in particular on its evolution needs to be also highlighted.
- <u>Axis III: Data Safeguarding</u> that sets different layers for data security and privacy assurance viewed under the perspectives of: (a) *attribute-based access control policies* that formally dictate the circumstances under which access requests to data assets should be granted, and are easily interpretable into policy enforcement rules; (b) *end-to-end symmetric key encryption* for data assets (before they are uploaded in the ICARUS platform) and secure tunnels for direct key sharing to authorized data consumers with active data contracts, (c) *multiple data anonymization methods* and guidelines for data providers to achieve the right balance in the "privacy vs utility" trade-off.
- <u>Axis VI: Data Analytics</u> considering 31 algorithms classified under *Basic Analytics*, *Machine Learning*, *Deep Learning* and *Visual Analytics*. In ICARUS, *data analytics and visualization* follows a step-wise approach that is designed

taking into account the key steps that are typical to any data analytics approach (containing the workflow definition, the algorithms execution and the visualization activities). The current data analytics practices in the ICARUS demonstrators are extensively discussed in order to understand the baseline in the different aviation stakeholders that ICARUS will need to overcome.

- Axis V: Data Sharing that initially presents the ICARUS positioning in respect to the 12 dimensions along which data marketplaces can be examined (ranging from the type of core offering, participation & target audience, and domain, to pricing model and payment methods), according to [6]. Departing from the data-focused perspective, the *ICARUS Data Sharing Model* formalises all data attributes and qualities that affect, or are in any way relevant to, the ways in which data assets can be shared / traded. The *ICARUS Blockchain-enabled Data Policy and Assets Brokerage Framework* also elaborates on an advanced workflow that anticipates data assets exploration, smart contract drafting, smart contract validation and negotiation in order to capture the complex provider-consumer interactions and demonstrate how ICARUS envisions to enable the creation of structured, machine-processable data contracts for the aviation industry, whilst maintaining the data owner in control of the provided data [7].

In all such methods, the ICARUS metadata schema (that features core metadata, semantic metadata, distribution metadata, sharing metadata and preservation metadata) and the ICARUS common aviation data model (constructed taking into account the Airport Community Recommended Information Services - ACRIS [8], the Airport Collaborative Decision-Making - A-CDM [9], the Aeronautical Information Exchange Model - AIXM [10], the IATA Standard Schedules Information – SSIM [11], the NASA ATM Ontology [12], and the UN/CEFACT Core Component Technical Specification - CCTS [13].

6 ICARUS Platform Implementation

In brief, the ICARUS big data analytics and sharing platform demonstrates the following key features: (a) End-to-End Data Security allowing to encrypt and check-in data through an on-premise environment, (b) Trusted Data Sharing for creating, signing and validating smart data contracts in an immutable manner to acquire aviation-related data, (c) Advanced Access Control to regulate access to the privately owned data assets through declarative authorization policies, (d) Secure and Private Analytics Spaces for designing and executing analytics and "applications" in private sandbox environments, (e) Intuitive Data Exploration in order to find, understand and explore aviation-related data, and (f) Effortless Data Linking that aims at curating, mapping and linking the privately owned data assets with external data based on a common data model.

The ICARUS platform practically consists of the Core Cloud Platform, the On-Premise Environment (installed in the premises of the data providers and data consumers) and the Secure and Private Analytics Spaces (spawn on demand in the ICARUS cloud infrastructures). Overall, the ICARUS platform architecture is a modular architecture and is composed by multiple components, that were designed with distinct roles, scope and concern separation to deliver the envisioned platform features. The functionalities provided by the ICARUS beta platform are described from the end-user perspective in 3 core workflows:

- **Data asset check-in** workflow that concerns how a data provider can upload data (as depicted in Figure 3).
- **Data asset search and acquisition** workflow that explains how a data consumer can search for data assets in the marketplace and purchase them (as depicted in Figure 4).

- **Data analytics and visualization** workflow that describes how a data analytics workflow is designed, executed and visualized in intuitive diagrams.

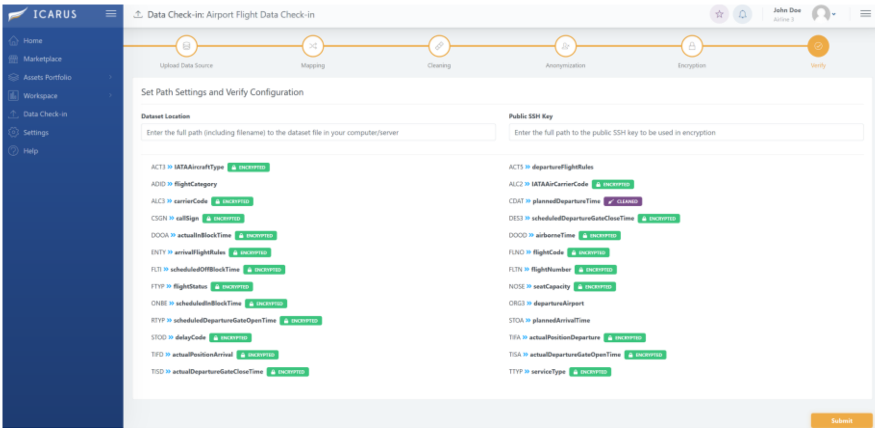


Fig. 3. ICARUS Platform: Data Checkin Configuration.

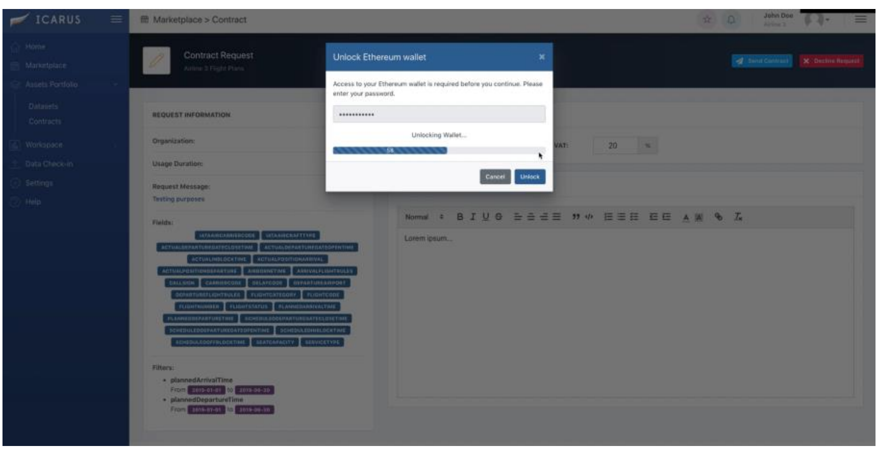


Fig. 4. ICARUS Platform: Data Acquisition – Draft Contract Signature.

7 Conclusions and Next Steps

Technology innovation through data platforms has the credentials to accelerate digital transformation and allow any industry to respond to new questions by leveraging its “data” goldmine. The ICARUS platform aims at building a novel data value chain in the aviation-related sectors, acting as multiplier of the “combined” data value that can be accrued, shared and traded. Using technologies that are currently on the rise (e.g. big data analytics, deep learning, semantic data enrichment, and blockchain powered data sharing), ICARUS attempts to address critical barriers for the adoption of Big Data in the aviation industry (i.e. data fragmentation, data provenance, data licensing and ownership), and will enable aviation-related big data scenarios for digital transformation, through a multi-sided platform that will allow exploration, curation, integration and deep analysis of original, synthesized and derivative data characterized by different velocity, variety and volume in a trusted and fair manner.

Future steps along our work in ICARUS include: (a) Access to external beta users to the ICARUS beta platform; (b) Iterative releases of the ICARUS platform to deliver new features and address the feedback acquired by the aviation data value chain stakeholders; (c) Demonstration of the business impact and technology excellence of the ICARUS platform through the ICARUS demonstrators.

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