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Privacy in the Skies and Screens: A Survey of IoT Aerospace Systems and Mobile Application Privacy Policies

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Abstract—**The rapid integration of Internet of Things (IoT) devices and mobile applications across several industries, including health and aerospace, has revolutionized operational efficiency, passenger experience, and safety, in these fields. However, as these devices and applications become more used, the concerns regarding privacy and cybersecurity also increase. Though IoT devices are low-powered and small, they face critical issues supporting traditional security protocols, making them more susceptible to cyber threats.**

Beyond IoT, mobile applications - whether everyday consumer apps or specialized aerospace software—are essential for both operations and customer interactions. These devices usually collect and retain many users' personal data, and are transmitted via insecure networks, raising data breach concerns. In sectors like aviation and aerospace, where flight data, sensitive information, and real-time systems are consistently being shared, privacy-enhancing technologies such as encryption, anonymization, and secure authentication are essential to minimize possible attacks.

This work explores the state-of-the-art on privacy policies for IoT systems and mobile applications, specifically in aeronautics, and provides recommendations for integrating robust privacy and security measures into these technologies.

Index Terms—**Aircraft, Internet of Things, Mobile Applications, Privacy Policies, Space Systems.**

I. Introduction

The Internet of Things (IoT) connects a wide range of physical devices through the Internet, allowing them to communicate and share different types of data. By inserting sensors and software into everyday objects, IoT transforms them into ”smart” devices that can collect, transmit, and analyze data without human intervention. These “smart” devices include items like household appliances, industrial machinery, vehicles, and healthcare equipment.

IoT has significant applications across several industries, such as healthcare, manufacturing, agriculture, and smart cities, improving their efficiency and automation. IoT enables real-time monitoring, predictive maintenance, and data-driven decision-making, and enhances everyday life through smart homes and connected devices. IoT has the potential to revolutionize industries, improve quality of life, and create new opportunities for innovation.

Despite all of these benefits, IoT faces challenges like data security, privacy, and device compatibility, and as the technology continues to expand, addressing these challenges is crucial.

Mobile phones have become an integral part of our daily lives; however, concerns about data security and privacy have intensified. Many applications gather users' sensitive information, including personal data like SSNs, credit or debit card details, and location data, often without user consent or clear disclosure. These applications also retain this data even after account deletion or uninstallation [1], but this information is not disclosed in the privacy policy or anywhere else. Although privacy policies exist, they are often unclear and lack transparency regarding data sharing, collection, and protection practices, and are also often vague, complex, or non-existent. Regulatory frameworks such as GDPR, CCPA, and COPPA strive to enforce user control and transparency, but compliance is inconsistent across platforms. Concerns about lack of informed consent, third-party tracking, and lack of security measures emphasize the need for robust privacy assessments and user-friendly policy designs.

These privacy and security challenges are not limited to mobile applications but extend to critical domains such as IoT and aerospace mobile applications. The integration of cybersecurity, the Internet of Things (IoT), and aerospace mobile applications represents a crucial intersection in the modern technological landscape. As IoT devices become increasingly prevalent in aerospace systems, mobile applications are utilized to manage and monitor critical operations, creating a complex ecosystem that relies on seamless communication and data exchange. However, this interconnectivity also exposes these systems to potential cybersecurity threats, as mobile applications and IoT devices become attractive targets for cyberattacks. Ensuring the security of aerospace mobile apps and IoT-enabled systems is vital for protecting sensitive operational data, safeguarding safety protocols, and preventing unauthorized access, which could jeopardize mission success or safety, as shown in Figure 1.

This paper presents an overview of the current state of the art of privacy polices in consumer IoT systems, mobile applications, and aircraft. The rest of the paper is organized as follows: Section 2 presents the state of the art in the privacy policies for consumer IoT systems. Section III discusses some privacy policies in Mobile Applications. Section IV presents privacy policies in the context of IoT Systems in Aircraft and Space Systems. Section V, introduces data privacy issues with airline passengers' mobile applications. Section VI

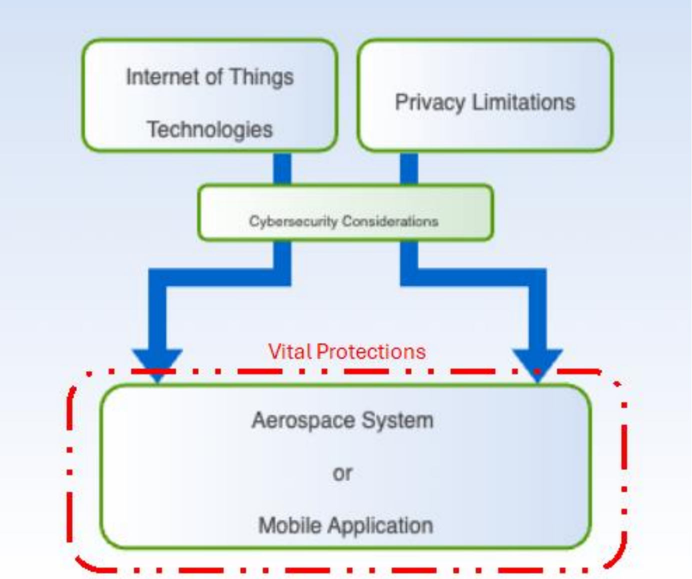

Fig. 1. Correlation between Cybersecurity, IoT, and privacy limitations as applicable to aerospace and mobile applications (Diagram by Rosa Szurgot)

Fig. 2. Consumer IoT

explains about data privacy issues in aerospace systems. Section VII, gives an analysis and recommendations of IoT implementations. Finally, Section VIII states the conclusions.

II. IoT Consumer Systems Privacy Policies

Consumer IoT systems are smart devices and technologies designed to make our lives easier in our daily routines. IoT systems connect different devices, allowing them to collect and share data to improve convenience, save time, and make things more efficient. Some examples include smart home devices like thermostats, security cameras, fitness trackers, and voice assistants. These systems rely on sensors, the cloud, and communication networks and protocols to offer real-time updates, automation, and remote control, often providing also benefits like energy savings, health monitoring, and enhanced home security, as shown in Figure 2. Security policies in IoT consumer systems are essential for keeping personal data safe, ensuring devices work properly, and preventing unauthorized access to these data. Since IoT devices gather sensitive information, like health data and user habits, it is important to have strong security to avoid data breaches, identity theft, and in general misuse of the information. Without security protections, IoT systems are at risk of cyberattacks that could compromise the privacy and safety of the users. These policies provide guidelines on how data should be handled, encrypted, and shared, while also ensuring devices are regularly updated and monitored for threats. These measures not only reduce risks but also build trust with users and safeguard privacy.

Authors of [2] conducted a review and comparison of the privacy policies and practices of six popular IoT devices used by end users: Amazon Echo, Google Home, Fitbit, Ecobee, Nest Smart, and Rachio Smart. The study presented varying results in terms of privacy policies across the devices. Manufacturers explained how sensor data is collected, along with extra information about the network itself. In particular, only one manufacturer disclosed that the collected data could be used by the company itself. The privacy policies were categorized into two types: data that users could share with consent and data that companies could share without user consent. All the policies showed that there were measures in place to protect the data. To further assess these practices, the authors conducted experiments using two voice assistants to track the generated traffic and verify the accuracy of the privacy policies. The results of these experiments were found to be satisfactory, the privacy policies were used in every case.

In [3], the authors conducted a study on the security and privacy challenges faced by IoT systems, identifying potential threats and proposing a set of countermeasures. These countermeasures were categorized into two main areas: the communication level (networking devices) and the edge nodes (smart devices). For the edge nodes, the authors recommended methods for detecting malicious firmware and malware, applying cryptography to encrypt data, updating node firmware, using intrusion detection systems, and increasing user awareness about security. At the communication level, the authors discourage the use of non-standard proprietary protocols, minimize interference from other wireless technologies, enable security modes, ensure anonymity, use authentication methods, implement network segmentation, and use mechanisms to prevent packet duplication and modification. In a similar line, the authors of [4] discuss the challenges of IoT security, privacy, safety, and ethics. They presented several privacy risks, like the ability to identify users through shared data, track and localize them, and create profiles based on behavioral patterns or other personal details. To address these concerns, they suggest best practices for securing IoT devices, including the use of hardware with tamper resistance, minimizing the amount of personal data collected and shared, using strong authentication methods, regularly updating firmware, enforcing access controls, and having mechanisms to prevent device identity spoofing.

Authors of [5] explore the security, privacy, and ethical issues faced by IoT users, while also looking at the different laws and standards adopted by countries to help reduce IoT system vulnerabilities. The paper emphasizes the risks that smart contracts face, such as malware injections, man-in-the-middle attacks, and mishandled exceptions. Since smart contracts often require personally identifiable information, there is a risk of data leakage if adequate security measures are not in place. But despite these concerns, there is no current global framework that regulates the security of smart contracts. On the ethical side, the authors highlight challenges such as the difficulty in identifying the owner of IoT devices, the unpredictable behavior of these devices, the gray lines between public and private information, and the potential life-threatening risks of IoT in healthcare. While several countries have implemented laws to protect user data, international organizations like ISO (International Organization for Standardization), ITU (International Telecommunication Union), IEEE (Institution for Electrical and Electronics Engineers), and IEC (International Electrotechnical Commission) have established standards to promote smart device interoperability, secure data exchange, and support privacy and security in IoT systems, including innovations in edge computing for IoT.

Continuing with these security concerns, the authors of [6] developed a software module with the goal of enforcing privacy policies at the edge nodes, specifically to protect sensitive user information. This module processes data received from the edge nodes using a set of policies to control how much information is shared with local or remote applications. Their testbed, which included a home surveillance system, showed that while the module successfully enhanced privacy, it did lead to some overhead in terms of latency and throughput due to the processing involved.

The focus on privacy and context-aware policy enforcement is also explored in [7], where the authors proposed a framework to model privacy policies within IoT systems, particularly in smart buildings. The framework emphasizes the role of factors like location and time in determining the context of IoT devices. It uses a tree-like structure to classify elements such as data collection frequency, retention, and recipients of the data, and convert privacy policies into machine-readable formats that can be applied in software modules. This approach ensures that privacy policies are consistently applied and customized to fit the specific context of each IoT system.

To address the challenges of real-time decision-making and reduce cloud dependency, the authors of [8] proposed a new layered IoT model, which integrates the concepts of edge and fog computing as shown in Figure 3. This model consists of three main layers: the device layer, the cloud layer, and the end-user layer. The device layer includes wireless sensors and communication protocols for real-time data collection, which is then processed in the cloud layer. Here, the data undergoes noise removal, analysis, and AI-based decision-making. However, to address security and privacy concerns at the end-user layer and reduce latency, two more layers are added; edge computing which enables real-time decisions directly at the device level while still sending data to the cloud for storage, and fog computing leverages more powerful, local resources for even faster processing, although it introduces new security and privacy challenges that must be addressed.

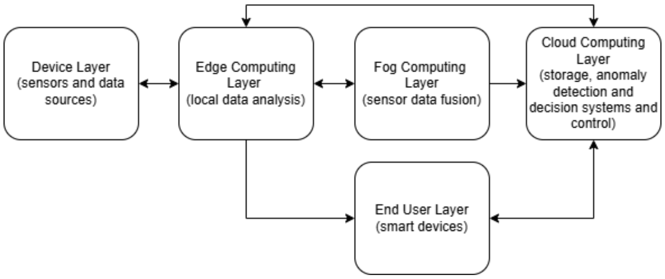

Fig. 3. IoT layered model [8]

For IoT wearables (smartwatches, fitness trackers, smart clothing, smart shoes, smart rings, smart glasses), the authors of [9] proposed an ontology designed to address the management of privacy risks associated with wearables. This ontology is based on the NIST IR 8228, a publication from the National Institute of Standards and Technology, which provides guidance on understanding and managing the cybersecurity and privacy risks of Internet of Things (IoT) devices. NIST IR 8228 particularly focuses on helping organizations unfamiliar with IoT security concerns, highlighting the challenges of managing these risks compared to traditional Information Technology (IT) systems. The proposed ontology enables wearable device vendors to automate privacy compliance, ensuring that data is collected and transmitted securely. Additionally, the authors introduced a methodology for utilizing Natural Language Processing (NLP) to extract privacy expectations, risk mitigation strategies, and relevant regulations from the privacy policies of the wearables devices.

In a similar approach, the authors of [10] developed a software tool to create a document collection for Natural Language Processing (NLP)-based semantic modeling. The software automates the process of collecting the links to IoT products, then, it creates a list of manufacturers, searches their websites for privacy policies, downloads them, and cleans up the content. The authors analyzed over 57,000 smart products, discovering 6,161 unique manufacturers. They collected 780 privacy policies in English, where 592 of them were unique. They only used the policies that contained at least 1,000 characters. As a result, they stated that the semantic model built from this data can be used to create methods for analyzing these policies, helping to make them more transparent and understandable for users.

III. Privacy Policies in Mobile Applications

With the ongoing use of mobile applications, it is important for users to be aware of what data is collected, shared, or misused by these artifacts. Therefore, it is essential to examine whether privacy policies mention these practices and comply with regulatory frameworks. The authors of [11] analyzed the inconsistencies between the mobile applications' privacy policies and their corresponding data-handling behaviors, describing the risks these discrepancies pose to privacy policies. They analyzed 68,051 Android applications from the Google Play Store, categorized under the Designed for Families (DFF) program and the analysis uncovered serious problems with regards to children's privacy, secure transmission practices, and third-party data sharing. The results showed that 30.6% of the applications claimed that they did not gather data from children but were identified as transmitting device identifiers related to them. Also, the analysis emphasizes important transparency problems in third-party data sharing, where only 22% disclosed their data-sharing partners and 75% of the applications depended on external services. Several developers utilized disclaimers for shifting the responsibility of third-party data handling creating ambiguity for users. The study also found that over 13.8% of applications transmit user identifiers without encryption, resulting in lack of care in secure transmission practices. Some developers claim that they implement strong security mechanisms, yet undermine user trust by including disclaimers that state that they cannot guarantee security. The analysis concluded by saying that the existing notice and consent privacy framework is inefficient, often leading to incomplete, obscure, or contradictory privacy policies.

Some applications do not comply with the regulatory frameworks, so the authors of [12] present a dynamic analysis framework called 3PDroid that's designed for assessing Android applications' compliance with Google Play privacy guidelines, particularly concerning third-party data sharing practices and access to privacy sensitive information (PSI). They analyzed over 5,473 applications and checked how well they followed the privacy rules. The study identified that only 5.5.% of the applications completely complied with Google Play's privacy guidelines whereas the remaining 94.5% were not compliant. Many of these applications either did not disclose the third-party data sharing practices or lacked valid privacy policies, despite accessing important information such as Wi-Fi status, location, and phone state. The study successfully analyzed 92.4% of the applications with fewer failures due to emulator compatibility issues and geographic restrictions. It also showed high precision in finding privacy policy pages and assessing compliance, with robust accuracy and recall metrics for third-party data-sharing analysis. Manual verification of 3PDroid's machine learning components (CR Checker and 3P Detector) further validated its reliability, showing strong precision, sensitivity, and specificity. The study concludes that, while many Android applications access user's personal information, only a few meet or follow privacy compliance requirements. 3PDroid provides a novel solution for privacy assessment during runtime, with future research aiming to expand on using machine learning techniques and improving third-party library detection capabilities.

To check if the iOS applications also exhibit the same behavior, the authors of [13] analyze the practices of 24,000 Android and iOS applications. Although Apple is known for emphasizing users' privacy, the sharing of user identifiers and third-party tracking were widespread on both Android and iOS platforms, including in applications designed for children. The study found privacy law violations in the UK, US, and EU that included third-party tracking without consent and lack of transparency in handling of data. Despite iOS having fewer advertising-related trackers, iOS apps often accessed children's locations more frequently than Android applications, emphasizing violations such as sharing personally identifiable information PII, lack of user content, and third-party tracking. These activities are performed without parental consent, cross-border data transfers to countries with a lack of data protection and showed little transparency in tracking mechanisms. To address the issue, the authors designed an automated, scalable methodology for comparing and analyzing application related privacy standards. They also provided the largest privacy analysis of iOS apps since 2013 and offered insights into platform governance and regulatory implications.

Some applications also collect users' personal health data, such as reproductive information. The paper [14] delves into the privacy practices of 30 popular menstrual tracking applications with more than 200 million downloads. These applications track a large range of sensitive information such as reproductive health, users' menstrual cycles, and at times sexual activity, raising issues about how user privacy is handled. The analysis focused on three main questions: how often developers inform the users about privacy policies, whether the policies are understandable, and if the application's behavior aligns with the provided policies. The researchers used a combination of quantitative and qualitative methods to assess the application's data practices and privacy policies. The study analyzed that over 70% of the applications offered easy access to privacy policies, where some applications had no policy provided at all. Many policies were ambiguous, most of the apps gathered more data than they claimed, frequently sharing this data with third parties without user consent. The overall conclusion of the analysis is that there are significant gaps in the transparency of privacy practices, especially regarding personal reproductive health data. The authors recommend that application developers provide comprehensive privacy policies and provide users more control over their data.

Likewise, another study focused on the data collected by menstrual applications where the authors of [15] examined the security, privacy, and data sharing practices of the prominent women's health (mHealth) applications, emphasizing legal and ethical concerns. Since health-related applications collect a large set of users' sensitive data, it is important that there is effective legal and ethical need for privacy standards. The study found that all the applications collected personal health-related data including location and behavioral tracking where 61% of the applications collected location that raised concerns about the extent of personal privacy and surveillance. Among the applications, only 70% offered a privacy policy, and 52% asked for users' consent, leaving a notable number of applications lacking accessible, clear policies or user consent. Furthermore, 13% of the applications collected data from users before obtaining their consent, which violates privacy expectations. Additionally, 57% of the applications were vulnerable to unauthorized access, as they did not present information on data security. Many applications did not comply with regulations like GDPR, which raises concerns regarding women's reproductive health data. The study concludes that applications in the mHealth industry have to be transparent and pose strong privacy policies to protect sensitive data.

As voice-activated technologies are actively integrated into our daily lives, understanding the privacy concerns of these applications is more important than ever. The authors of [16] examined the quality, usability, and effectiveness of privacy policies for voice application on Google Assistant and Amazon Alexa. They analyzed 2,201 Google Assistant actions and 64,720 Alexa skills as shown in Figure 4, identifying broken or missing privacy policy links, discrepancies between privacy policies, vague policies, and ambiguous app descriptions. The official Google voice-apps and Amazon also failed to comply with privacy policy requirements. The authors designed a natural language based (NLP) approach to compare the privacy policies with application descriptions, finding incomplete disclosures and undisclosed data practices. They also conducted a user study with 91 participants, where 66% mentioned that they never read privacy policies, and attributed this to the complexity, length, and inaccessibility of the policy. The results emphasize the need for improved transparency in privacy policies, stronger regulatory oversight, better user-friendly privacy disclosures, and strong certification processes. They also recommend offering policy accessibility through voice commands to improve usability and support informed privacy decisions.

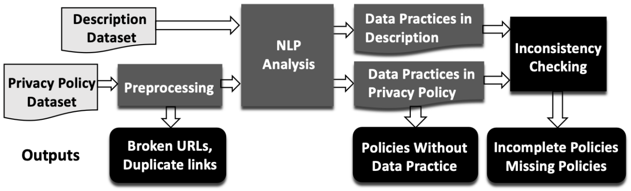
Description Dataset
Privacy Policy Dataset
Preprocessing
NLP Analysis
Data Practices in Description
Data Practices in Privacy Policy
Inconsistency Checking
Outputs
Broken URLs, Duplicate links
Policies Without Data Practice
Incomplete Policies Missing Policies

Fig. 4. Processing pipeline of privacy policy analysis. [16]

Another study related to mHealth applications, investigated by the authors of [17], analyzed existing works that examined the privacy of mHealth applications. They found the important privacy components, evaluated several criteria and scoring methods, and established a taxonomy for categorizing privacy assessment techniques.

The authors employed a systematic approach across several academic databases, considering the studies published from 2009 where a total of 24 studies were selected for the final analysis. 50% of the analysis included privacy aspects, while 33% considered security and privacy evaluations, and the remaining 17% included privacy within broader app assessments. Privacy assessment criteria included legal regularities such as GDPR, HIPAA recommendations where some of the assessed items included security approaches such as access control and authentications, data communication content and destinations. The analysis utilized several scoring techniques to compare and examine privacy levels among the applications. The results emphasized the significant challenges in the privacy assessment of mHealth applications, such as the lack of objective methods, inconsistent evaluation methodologies, and limited utilization of technical analysis.

To analyze why users are not interested in reading privacy policies, the authors of [18] analyzed the user's engagement with privacy policies, investigating barriers such as complexity, poor design, motivations, and comprehension challenges. The analysis emphasizes the importance of user-friendly designs, and educational or training programs to improve privacy awareness and trust. The study examined the user responses, identifying that 77% claimed to have reviewed the policies but only a small percentage of users read updates regularly or completely engaged with the privacy content. Concerns such as the complexity of privacy policies, legal jargons, and poor design or formatting led to deter engagement. It was also found that only 18.4% of participants communicated the difficulties in understanding the policies. Though users were well known about the Personally Identifiable Information (PII) location tracking dangers, only 55% shared the poor comprehension regarding the location data risks. Additionally, 80% expressed a desire for direct consent checkboxes rather than long, passive agreements. The study analyzed the reasons users avoid reading the privacy policies and highlighted the discrepancies between perceived and actual understanding of these privacy policies. The authors recommended implementing interactive and segmented privacy policies and suggested to adopt or design policies similar to Facebook-style policies, which included clickable sections, videos, and FAQs.

As concerns over data privacy are increasing, it is important to examine how mobile applications handle user data. The authors of [19] developed a tool called GUILeak to check whether mobile applications collect user data and to detect privacy violations. It compares the privacy policy statements with the data that users provide in the GUI input fields rather than analyzing the source code. The authors incorporated WordNet which improved the detection of violations by matching the privacy terms with the input fields. They analyzed the bytecode (not the source code) and tracked the data flow using popular tools like FlowDroid and SUSI for network tracking. The study found 21 major and 18 minor violations, in which some applications collected user private data without explicitly mentioning it in their privacy statements. The study faced challenges with file-based and encrypted data leaks and recommended better tracking approaches. The GUILeak outperformed the existing tools by matching actual user inputs to policies and achieved 84% accuracy.

To examine privacy compliance in Android applications at scale, the authors of [20] developed an automated framework, MAPS: Scaling Privacy Compliance Analysis to a Million applicationss, to assess privacy compliance in Android applications. MAPS evaluated over 1 million applications to detect privacy violations using Natural Language Processing (NLP) and automated extraction and analysis of privacy policies and app behavior. The framework identified that many applications lacked a privacy policy, and some applications did not reveal their data collection practices. Results showed that several applications did not comply with GDPR regulations. Consequently, the authors advocate for stronger enforcement, better privacy policies, and transparency in handling users' data.

IV. IoT Systems in Aircraft and Space Systems Privacy Policies

Trust serves as a critical foundation for both the establishment and endurance of strong relationships. When trust erodes or is absent, those connections are vulnerable to failure or dissolution. As we know, the Internet is hardly associated with 'trust' or 'trustworthy'. The common human being is increasingly aware of the negative aspects of the Internet and technology in general. This lack of trust causes people to be more mindful of their data and to try to avoid or limit exposure to the Internet. This is applicable to the aerospace industry as well. But that task is rather impossible in the present age [21]. A survey by authors [22] discusses the foundational ethical issues of IoT. The authors argue that trust is reliant on ethical issues such as privacy, informed consent, information security, and physical safety and that these issues exist as concatenation and integrate into myriad ways. This is essential to recognize as when there is a breach in the user's data, their privacy and security are compromised and informed consent is disregarded. This leads to trust issues among the user which in turn can spark a series of questions in the user's mind as to who or what can they trust? or how trustworthy is this particular organization or object? ultimately causing the feeling of panic and insecurity among the individual.

Trust dictates the world of IoT alongside as these smart 'things' are being incorporated into our daily routines increasingly. For users to rely confidently on IoT and smart devices, they need to first make sure that these components are trustworthy. They need to believe and trust these devices that their data is secured. To combat this problem of 'untrustworthy' devices, various Trust Frameworks are being incorporated into the markets. These frameworks can be a potential step to bridge the issue of trust. Trust can be deciphered by trading 'assurance' by the involved parties. The U.S. government now plans, fabricates, and deploys Trust Frameworks [23]. Similarly, governments can enact laws to protect their citizens which in turn will allow the users to trust these smart devices knowing that there are laws enacted in their favor.

V. Data Privacy Issues with Airline Passengers' Mobile Applications

For airline passengers, unease about the protection of their personal details is on the rise when using airline mobile apps. While these apps aim to simplify travel with services like easy ticket purchases, flight management, and tailored suggestions, they commonly gather substantial amounts of private user data. This practice fuels worry regarding how this data might be employed, where it is stored, and whether it could be disclosed.

Many airline web applications request extensive permissions that may not be strictly necessary for their functionality. For example, they may ask for access to a passenger's location, contacts, camera, and microphone. While these permissions can improve the app's functionality (such as offering personalized travel recommendations or using location-based services), they can also lead to privacy risks. If apps collect too much data, or if they request permissions that are not aligned with the core service, passengers may feel uneasy about how much personal information is being gathered without their clear consent.

Airline web applications handle sensitive personal information, such as full names, passport numbers, credit card details, and flight history, therefore if this data is not properly encrypted or stored securely, it becomes vulnerable to hacking and cyberattacks. In the past, there have been incidents where hackers have gained unauthorized access to airline databases, leading to potential identity theft or financial fraud. The risk is even greater when passengers use unsecured networks, such as public WiFi in airports or onboard flights.

A significant concern is how airlines share passenger data with third parties, such as advertising companies, business partners, or other service providers. The privacy policies of these third-party entities may not be as strict as those of the airline, potentially exposing passengers' information to misuse and even if the sharing is used for improving services, passengers may not always know if their data will be shared or sold.

One of the major privacy concerns is the lack of clear and easily accessible information regarding how airlines use the data they collect. Privacy policies are often lengthy, difficult to understand, and buried deep within the app's settings. Passengers may not always be aware of what personal information they are providing, how it will be used, or how long it will be retained. Without transparency, passengers may feel distrustful about how their data is being managed [24].

Aviation applications may track users' behaviors, preferences, and purchasing patterns to create detailed profiles. These profiles can then be used to target passengers with personalized marketing campaigns or to predict their future travel behaviors. While this can enhance the customer experience, it also raises concerns about excessive surveillance and the potential for intrusive advertising. The line between personalization and privacy invasion can be blurry, leaving passengers uncomfortable with how much is known about them.

Another issue is how long airlines keep personal data. Many mobile applications retain data for long periods, even after the passenger has completed their flight or deleted their account raising concerns about post-use privacy. Therefore, if this data is not properly disposed of or anonymized, it can remain vulnerable to breaches or misuse.

For international travelers, privacy concerns are increased by the possibility of data being shared or transferred between different countries. Different countries have cross-border data protection laws, and passengers may not always be aware of where their data is being processed. For example, a U.S.-based airline could share data with partners in countries that do not have strict data protection laws, compromising the privacy of the passenger [25].

The degree to which passengers can control the data that airlines collect is another issue. Many apps may require passengers to agree to broad terms of service and privacy policies without offering granular control over what data is collected. For instance, users might be forced to share certain personal details just to book a flight, without the option to opt out of data collection practices that aren't strictly necessary for the transaction.

VI. Data Privacy Issues in Aerospace Systems

In the aerospace industry, whether avionic systems or spacecraft systems, data privacy issues are a growing concern as both commercial and military systems increasingly rely on advanced technologies responsible for integrating aircraft, autonomous systems, and big data analytics. As aerospace systems become more integrated with digital networks, the collection, processing, and sharing of sensitive data presents several risks.

The authors of [26] reiterate mobile applications serving a variety of airlines often handle large amounts of personal and sensitive data, particularly in commercial aviation. This data includes passenger information (e.g., names, passport details, flight histories, payment details), crew data (e.g., identification numbers, medical records, flight logs), health-related data (e.g., monitoring systems that track pilots' physical and mental states), the collection of such data is critical for the smooth operation of airlines, air traffic control, and safety systems. However, improper handling or breaches of this data could lead to identity theft, fraud, or misuse. Passengers and crew members may be unaware of the extent to which their data is collected or shared with third parties, such as travel agencies, government authorities, or marketing companies.

Modern aircraft are equipped with sophisticated communication and navigation systems that rely on vast amounts of data transmission. For example, real-time aircraft tracking systems send data about location, altitude, speed, heading, and other parameters to ground-based systems. In-flight entertainment systems may collect data on passenger preferences and usage patterns. With the continuous development of modern aircraft, such as the latest concept release of the Airbus A390, the promise to uphold emerging technologies in the field of aviation is a testament to the indomitable spirit of innovation from the major commercial aviation players and aviation pioneers. Autonomous flight systems are continuously gathering data to enhance the safety and efficiency of flight operations.

Although these technologies improve safety and efficiency, they also introduce significant risks. The authors of [27] emphasize that hackers may attempt to intercept or spoof communications between aircraft and ground systems. Unauthorized access to cockpit controls or in-flight data systems could jeopardize both privacy and safety. In addition, there is the risk that the data is used for surveillance or targeted advertising, raising concerns about consent and data protection [28].

Aircraft systems generate enormous amounts of maintenance and diagnostic data, which are vital to ensuring the safety and functionality of the aircraft. For example: Engine health monitoring systems continuously track engine performance and wear. Flight data recorders capture detailed information on every flight, from altitude to fuel consumption to system malfunctions. This type of data is often transmitted to ground-based systems for analysis. While this process enhances safety, it also creates a potential vulnerability. If maintenance data is accessed by unauthorized entities, it could lead to sabotage or the manipulation of the system's operation. Additionally, this data could be shared or sold to third-party service providers, raising concerns about how they could be used or exposed.

The aerospace industry relies heavily on third-party vendors for every service ranging from software development to data analysis. These service providers often have access to sensitive data generated by the aircraft, passengers, or crew. For example: Cloud storage services may host large volumes of data related to flight operations and passenger information. Data analytics firms may analyze patterns of air traffic, flight delays, and passenger preferences. Maintenance service providers may have access to diagnostic and operational data of aircraft. If these third parties do not follow stringent data privacy and security protocols, the data could be vulnerable to leaks, hacks, or misuse. Even when third parties are subject to agreements and non-disclosure contracts, they may still be susceptible to cyberattacks or may not have the necessary security infrastructure in place.

Governments have a big interest in collecting data related to aviation, particularly for national security and regulatory purposes, like air traffic control systems, which monitor and track aircraft movement in real-time. Passenger data-sharing agreements require airlines to provide sensitive passenger details to government agencies, such as immigration or customs authorities. While these measures may enhance safety, the collection and sharing of this data can raise privacy concerns. Passengers may not be fully aware of how their data is used by government agencies, or whether their information is being stored or shared with other countries. There is also the risk that sensitive data could be accessed by malicious actors or used for purposes beyond what was originally intended.

The NIST Special Publication 800-53 Rev. 5 Security Controls provides a comprehensive framework for safeguarding both the confidentiality and integrity of information systems, including those in aerospace systems. When addressing privacy concerns, several controls from the NIST 800-53 family are particularly relevant to aerospace systems, ensuring that sensitive data, including passenger and operational information, is protected. Specifically, the Privacy Controls (Appendix J) within NIST 800-53, such as AP-1 (Access Control for Privacy) and PL-8 (Privacy Policy and Procedures), ensure that aerospace organizations develop clear privacy policies and implement access control mechanisms that limit data access based on need-to-know principles. For example, the System and Communications Protection (SC) family of controls emphasize the importance of safeguarding data in transit and storage, applying encryption techniques and secure communication protocols, critical for aviation systems where data is transmitted between aircraft and ground stations. Additionally, the Media Protection (MP-5) control requires that data, especially personally identifiable information (PII), is securely wiped from storage media before disposal or reuse. The Configuration Management (CM-6) control ensures that privacy settings are maintained across systems and networks, preventing unauthorized changes that could compromise personal data. By implementing these NIST 800-53 controls, aerospace organizations can better secure privacy-sensitive data, such as passenger details, flight logs, and maintenance records, while mitigating risks associated with cyberattacks, data breaches, or improper access [29]. Aerospace systems and airline operations often store data for long periods to comply with regulatory requirements, optimize services, and enhance safety. However, the retention of large volumes of data raises several privacy issues: Unnecessary data retention–If passenger and operational data is retained longer than necessary, it increases the risk of unauthorized access or misuse. Failure to delete data–If data is not properly destroyed when it is no longer needed, it could remain vulnerable to cyberattacks or breaches. Regulatory frameworks, such as the General Data Protection Regulation (GDPR) in Europe, aim to address these issues by requiring organizations to limit data retention and ensure that personal data is either anonymized or securely erased once it is no longer required for its original purpose. The authors of [30] confirm that the aerospace industry is a high-value target for cybercriminals, given the sensitive nature of the data it handles and the potential for widespread disruption. Data breaches in the aerospace sector can involve not only the personal data of passengers and crew but also critical operational information, such as aircraft design and software codes, flight operation data, and air traffic control system vulnerabilities.

A data breach presents significant challenges for both airlines and their passengers. In a severe scenario, unauthorized access could compromise aircraft systems, potentially leading to physical damage or, in the most extreme cases, loss of life, and even if no direct harm results, a major breach can negatively impact an airline's reputation and erode passenger trust

The integration of new features and tools is an integral aspect of the new system; however, the integration of artificial intelligence (AI), machine learning, natural language processing, 5G, and 6G connectivity also creates new privacy issues. The analysis of data to improve safety, maximize route optimization, and improve customer service introduces potential misuse. With AI algorithms that may rely on passenger data for predictive models, it is essential to be aware of consent and data ownership. Although 5G networks create more efficiency for aircraft, ground stations, and passengers, it makes it easier for malicious actors to intercept data, therefore, requiring more awareness of safety protocols. Data about passengers, crew, and airplane's environment can be used for data misuse through the Internet of Things (IoT).

VII. Recommendations

Recent trends in privacy and security for mobile applications highlight the growing adoption of advanced natural language processing (NLP) techniques, such as semantic similarity models like BERT, to effectively align application behavior with privacy policy claims. Additionally, there is a notable shift toward integrating hybrid analysis methods, combining both static and dynamic techniques, to comprehensively detect data leaks. Robust encryption methods have become increasingly standard, particularly in securing sensitive aerospace and airline data, reflecting heightened concerns regarding unauthorized access during data transmission. Furthermore, strong security protocols for IoT devices, such as multi-factor authentication (MFA), secure communication channels, and regular software updates, are becoming essential, especially in critical areas like real-time flight tracking and maintenance. The implementation of AI-driven anomaly detection systems is another significant trend, providing proactive identification and alerts for suspicious activities, thereby ensuring rapid response and mitigation. Lastly, there is an intensified focus on regulatory compliance, with privacy policies increasingly aligned with international standards such as GDPR and NIST SP 800-53 Rev. 5, complemented by clear user consent mechanisms.

Despite these advancements, several gaps remain. Simple keyword extraction methods, such as regular expressions, have proven inadequate due to their inability to effectively capture nuanced language in privacy policies. Moreover, discrepancies frequently arise between stated privacy claims and actual application behaviors, largely because semantic consistencies are insufficiently verified. Existing frameworks often lack robust methods to thoroughly test user consent flows, risking unauthorized data collection. Similarly, static-only or dynamic-only analysis methods are insufficient, resulting in missed detections of subtle yet significant data leaks. IoT devices used within aviation contexts also suffer from inadequate security protocols, leaving them vulnerable to cyber threats and unauthorized access. Another critical gap is the absence or delayed response in detecting privacy breaches, primarily due to limited deployment of automated anomaly detection

TABLE I
ANALYSIS MATRIX

Aspect of Review	Current Issues	Recommended Methods	Expected Outcome / Benefit
Privacy Policy Analysis	Regular expressions insufficiently capture nuanced language	Advanced NLP, grammar-based extraction methods	Accurate keyword identification, better privacy compliance
Data Leak Detection	Static-only or dynamic-only analysis misses complex leaks	Combination of static and dynamic analysis	Comprehensive detection and prevention of data leaks
Data Encryption	Sensitive data in aerospace/airline apps inadequately protected	Robust encryption methods and standards (AES, RSA, etc.)	Protection of sensitive data, reduced risk of breaches
IoT Security	Weak security measures on IoT devices in aviation contexts	Strong IoT protocols, MFA, secure channels, regular updates	Increased protection from cyber threats, stable operations
AI-based Detection	Slow detection of anomalous activities or breaches	Implementation of AI-driven anomaly detection systems	Rapid breach identification, prompt mitigation
Regulatory Compliance	Privacy policies insufficiently aligned with GDPR, NIST guidelines	Regular compliance auditing, explicit alignment with standards	Global compliance, minimized legal risk, transparency

systems. Finally, inconsistencies persist between privacy policies and evolving international regulatory frameworks, posing ongoing compliance risks and potential legal liabilities.

To bridge these gaps, several methodologies are recommended. Employing advanced NLP and grammar-based parsing techniques for keyword extraction can greatly improve the accuracy of privacy assessments. Incorporating semantic similarity models like BERT will ensure a more precise alignment between application behavior and policy claims. Developing a comprehensive framework specifically designed to rigorously evaluate user consent flows is also necessary to enhance compliance and user trust. Additionally, combining dynamic and static analysis methods would significantly improve the detection and prevention of data leaks. For securing sensitive aerospace and airline data, robust encryption standards such as AES or RSA should be uniformly implemented. IoT security must be strengthened through regular software updates, secure communication channels, and multi-factor authentication protocols. Proactive deployment of AI-driven anomaly detection systems will facilitate early identification and mitigation of privacy breaches. Adopting secure application development practices, including secure coding techniques and regular penetration testing, will minimize vulnerabilities in airline and aerospace applications. Finally, regular compliance auditing and explicit alignment of privacy policies with standards such as GDPR and NIST SP 800-53 Rev. 5 will ensure global regulatory compliance, transparency, and legal safety. Integrating these recommendations will substantially enhance privacy and security measures, ensuring user trust and operational efficiency in mobile applications and aviation systems alike.

Table I systematically summarizes the current issues, recommended solutions, and anticipated outcomes related to privacy and security practices in mobile applications and aerospace systems. This structured representation helps visualize existing vulnerabilities and the effectiveness of proposed recommendations. By clearly aligning identified gaps with targeted methodological approaches and expected benefits, stakeholders can efficiently prioritize actions to enhance user trust, regulatory compliance, and overall system robustness.

VIII. CONCLUSION

In conclusion, this review underscores the critical importance of privacy and security in mobile applications and aerospace systems, highlighting both trends and persistent gaps that require targeted attention. Additionally, a recent survey of IoT aerospace systems further emphasizes the complexity and interconnectivity of modern aerospace technologies, outlining emerging vulnerabilities inherent to IoT integration within aviation infrastructures. This survey reinforces the need for robust, comprehensive security frameworks, including strong encryption methods, proactive anomaly detection systems, and rigorous compliance practices. Addressing these challenges through continuous research and development will be crucial in safeguarding IoT aerospace applications against evolving threats, ultimately ensuring reliability, privacy, and operational safety in aviation environments. Mobile application privacy policies often lack clarity about data-sharing practices, transparency, and can be vague, making it harder for users to understand them. Therefore, it is important to have stronger protection mechanisms, and automated compliance checks will assist users. Combining technical and legal efforts will ensure better data security. As IoT continues to grow in aviation, it's critical to make sure these systems are both innovative and secure. This will require ongoing research, teamwork across industries, and a strong focus on protecting both systems and users.

Mobile applications have significantly transformed the aviation industry by enhancing the customer experience, but they have also introduced privacy challenges. According to [32], the sensitive nature of the data airlines handle makes privacy protection extremely important. To address these concerns, airlines must prioritize transparency, secure data management, clear consent processes, and empower passengers with greater control over their personal data.

Data privacy issues in aerospace systems are complex and demand a balanced approach from both technological and regulatory perspectives. As the industry becomes increasingly reliant on digital systems, connected devices, and third-party services, the aerospace sector must implement robust security practices to protect sensitive information. This includes data encryption, clear data retention and deletion policies, transparency with passengers and crew, and full compliance with international data protection laws.

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