Development of the Explainable Intelligent Alternate Airport Assistant (EIAAA)

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Diversions, which occur when aircraft must land at an airport other than their original destination due to unforeseen circumstances such as technical malfunctions or medical emergencies, are complex events that require quick and informed decision-making. Currently, pilots must manually evaluate multiple sources of different types of information. To address this challenge, the German Aerospace Center developed the Explainable Intelligent Alternate Airport Assistant (EIAAA), a decision support tool designed for use in the cockpit. The system continuously monitors the flight situation, evaluates multiple categories of data, and recommends the three most suitable alternate airports. The system operates in distinct modes, allowing it to adapt its prioritization logic based on the nature of the situation. The system's explainability is a core feature that enables pilots to understand and trust its recommendations through transparent data visualization and decision logic. Simulations and preliminary evaluations demonstrate that the system significantly reduces pilots' cognitive load while aligning with their mental models and safety priorities. Integrating the system into normal flight operations allows pilots to become familiar with and confident in the system, facilitating its rapid adoption in emergency scenarios. Currently, the system is being prepared for a higher technology readiness level under the DLR HAWKEYE project. It represents a significant advancement in intelligent, transparent alternate airport support systems for modern aviation.

I. Nomenclature

ASAP	=	As soon as possible
ATC	=	Air Traffic Control
DLR	=	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
DODAR	=	Diagnose, Options, Decide, Act, Review
EFB	=	Electronic Flight Bag
EIAAA	=	Explainable Intelligent Alternate Airport Assistant
FORDEC	=	Facts, Options, Risks, Decision, Execution, Check
METAR	=	METeorological Aerodrome Report
NICo	=	Next Generation Intelligent Cockpit
SPORDEC	=	Situation Catch, Preliminary Actions, Options, Rating, Decision, Execution, Controlling

II. Introduction

In aviation, a diversion is defined as a situation when an aircraft lands at a different airport than originally planned. A common reason for this is a lack of fuel, for example because of night curfews, or weather conditions make a safe landing impossible. For this type of diversion, two alternative airports are identified in advance in the flight planning. However, there are also diversions due to technical malfunctions, medical emergencies, or other unforeseen events during the flight that make it impossible to reach neither the destination airport nor the preselected alternates. There are no official sources about the total number of such diversions. Literature refers to 0.2 % – 0.3 % of all flights in American

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and European airspace that had to interrupt their planned flight and land at another airport. The ongoing political instability around the world, the rising number of technical components in modern aircraft and the aging passenger population with a higher probability of medical incidents [1, 2], will increase the likelihood of unplanned events in the future. Obviously, in such unforeseen cases, alternative airports cannot be determined in advance. The aircrew must assess the situation by themselves and decide together on an alternative airport during flight [3]. This decision depends on several sources of information. Currently, this information is not processed in a central location in the cockpit but is provided separately by different systems in different formats. Weather information can be obtained from air traffic control (ATC), the weather briefing, or directly from the aircraft's weather radar. The aircraft's status is displayed to the crew on the ECAM and must be correlated with the associated digital procedural instructions. Information about handling passengers is communicated with Flight Operations via satellite phone. The decision making is based on pilot experience, weather information and the technical state of the aircraft. Furthermore, the remaining fuel and the impact on passenger and baggage transport from the alternative airport to the original destination play an important role, too. In case of a medical incident, possible medical care at the alternate is as well a factor to be considered.

The entire decision-making process can take up valuable time in the cockpit as many different sources of information are used and a structured decision-making tool like FORDEC, DODAR or SPORDEC [4] must be performed. Although several options are considered during this process, there is no guarantee that the final selection of an airport will be the most appropriate. Recent studies, for example in the German Aerospace Center (DLR) project *Next Generation Intelligent Cockpit* (NICo), have shown that this process can take up to 20 minutes [5]. In addition, the aircraft continues to fly at 450 kt (840 km/h) during the time it takes the crew to analyze and make decisions. Possible airports that were available at the start of the decision-making process may no longer be reachable. Conversely, it is possible that better options are by the time now within reach of the flight, but are not being considered by the crew.

The rest of the paper is structured as follows: Section 3 introduces an assistant system that supports and accelerates the alternate airport selection process. Section 4 will present the evaluation of the best alternate airport in our system. Section 5 provides an overview of the developed user interfaces, and Section 6 summarizes the challenges of establishing trust in a new assistant system.

III. Explainable Intelligent Alternate Airport Assistant

In order to accelerate and enhance the quality of the decision-making process, the prototype of the *Explainable Intelligent Alternate Airport Assistant* (EIAAA) has been developed by the DLR. A preliminary design of the user interface that has been validated by pilots is shown in figure 1.

The EIAAA is designed as an application for an Electronic Flight Bag (EFB) Class 2. An EFB Class 2 device takes the form of a commercial tablet, such as an iPad or a Windows-based device, and is mounted in the cockpit using an approved bracket. Class 2 EFBs are semi-integrated, thus they are not permanently installed in the aircraft, but are connected to the aircraft's power supply and receive data from certain onboard systems. This integration enables the EIAAA to monitor the current flight situation throughout the entire duration of the flight. This includes information about the aircraft itself, its flight path and the situation in the air and, via datalink, the situation on the ground. Currently, the EIAAA evaluates 16 categories of information in real time. This information ranges from basic details such as the availability of airports and runways, current and upcoming weather conditions, and traffic situations, to more specific information such as the estimated risks along planned and alternative flight routes, the political situation, airline rules, and passenger handling preferences. The system evaluates additional parameters within these categories. Additionally, dependencies between the parameters are checked.

EIAAA offers four different modes of operations: *1. Situational Awareness, 2. Medical, 3. Technical, 4. Land ASAP*. These modes were developed in workshops with professional pilots and represent the most abstract adaptation of the operating mode to the current situation. It is already foreseen that, in the future, this selection of the current operating mode will also be possible via external triggers, e.g. from the aircraft itself. Selecting a mode changes the weighting of the decision parameters, ensuring that the optimal alternate airport can be calculated according to the current situation. The EIAAA reacts to the current flight situation and recommends the three most appropriate alternate airports. One of the system's key objectives is to ensure that pilots can fully understand EIAAA's recommendations. This is achieved by providing a clear and concise evaluation of airports, which fosters trust in the automation and allows pilots to make a final decision rapidly and based on a comprehensive range of information.

Fig. 1 The alternate airport assistant was subjected to a series of tests on an EFB

IV. Evaluation of Alternate Airports

As previously stated, there are numerous reasons for a diversion. The reason for the diversion is, at its current stage of development, directly obtained by EIAAA from the crew via the user interface. The EIAAA can be operated in four modes: *1. Situational Awareness, 2. Medical, 3. Technical, 4. Land ASAP*. Situational Awareness acts as a general assessment, continuously operational in the background. In this mode, the analysis weights are distributed relatively evenly, while still considering the aircraft's current status, weather conditions, and further parameters. Three main parameters are ranked higher: the forecasted weather at the airport at the time of arrival, including the expected weather conditions along the flight trajectory to the specific airport, the available approach types for each runway, and the current capacity of the airport and surrounding airspace. The crew is presented with three possible alternate airports. This allows them to compare the system's recommendation with their mental model of the situation during low workload flight segments. In interviews, pilots reported that they are always aware of their current position on the flight route and their landing options. EIAAA's *Situational Awareness mode* supports exactly this mental model. This is an important first step in building trust between users and the system. If the system's suggestions match the assessments/expectations of the crew , trust in and willingness to accept EIAAA's recommendations will increase.

Contrary to the first mode, the modes *2. Medical, 3. Technical, 4. Land ASAP* modify the evaluation criteria to adapt to the specific circumstances that are currently prevailing. The Medical mode is designed for medical emergencies on board that require immediate hospital treatment. In this mode, flight time to an alternate airport and weather conditions en route and at the airport are prioritized. Additionally, this mode considers the current availability of medical care at the airport and travel time to the hospital. This parameter, in particular, has proven critical in analyses. Depending on the location of the hospital and airport as well as the current ground traffic, EIAAA's intelligent selection can save valuable time for the patient even after landing. All other decision parameters are also analyzed during each run. Their weighting is reduced in accordance with the concept.

So far, the crew has to manually select the appropriate *Technical mode*. In future, the mode selection should be done automatically in the event of a technical failure. Technical mode is intended for malfunctions for which continuing the flight to the destination airport is no longer reasonable or possible, yet the aircraft is still in a safe, airworthy condition. Unlike *Land ASAP mode*, the *Technical mode* allows the flight to continue safely for a certain time. Technical mode prioritizes approach types for available runways and flight time to the alternate airport. Additionally, it evaluates how far the runways and taxiways exceed the minima specified by the aircraft manufacturer for corresponding technical malfunctions. The evaluation also considers whether airline maintenance or general technical assistance are available at the alternate airport.

Unlike the previously described modes, which all assume an aircraft that is at least partially airworthy with an option for a longer flight time, the *Land ASAP mode* is designed to perform a safe landing as quickly as possible. In workshops with pilots, we analyzed a wide variety of reasons for such a time-critical landing. The results revealed that an urgent landing, regardless of the trigger, always leads to a high workload in the cockpit and, in some cases, a crew with limited ability to act. As with the previous modes, EIAAA considers the aircraft's condition and selects the optimal alternate airport according to the specified parameters. Three key parameters emerged from the workshop. The first was the expected weather at the alternate airport at the time of landing. The second was the remaining flight time to the alternate airport, including any necessary maneuvers to transition from the current aircraft altitude and configuration to landing. Workshop participants rated the available approach procedures as highly important, considering the current crew and aircraft status. These parameters are given higher weights in *Land ASAP mode*. All other safety-critical parameters are also checked by the system, to ensure adherence to their limits.

For the time being, the aircraft's technical condition is included in the alternate airport assessment, but automated data retrieval directly from the aircraft is still under development. In the next development step, EIAAA will consider the aircraft's technical condition and current restrictions at any given time, automatically. Through mode selection, the main reason for the diversion is made available to the system by the crew. Special attention is given to the aircraft's capabilities and the requirements that result in the selection of an alternate airport. For example, the failure of an engine reduces the crosswind landing capability, which must be included in the subsequent EIAAA assessment algorithm. Failure of flaps or thrust reversers significantly increases the required landing distance. Additionally, more complex failures in the hydraulic or electrical systems lead to restrictions that are not immediately apparent. These must be considered when selecting an optimal alternate airport. The constraints must be addressed, especially when the aircraft's assistance and automation functions are limited, and the expected workload in the cockpit is high. Pilots emphasized that failures leading to a reduction in aircraft's autoland capability are considered as serious. However, human factors must also be considered in the assessment. Is the proposed airport familiar to the crew? Does it require a captain's landing? These "softer" parameters are already implemented in the intelligent selection of an optimal alternate airport.

In addition to the obvious hard factors that influence the selection of an alternate airport, the EIAAA also considers less apparent factors that nevertheless have a significant impact on an intelligent selection. E.g., this includes the analysis of the flight route to the alternate airport. What risks/threads do this new route bring to the flight? It is of no benefit to the crew if the proposed airport has optimal weather conditions, but the new flight route passes through a thunderstorm area or a closed airspace. The pilots who participated in developing the system requested that the weather analysis always consider current weather conditions and anticipated changes up to the predicted landing time. Only then a given recommendation will remain valid until a safe landing is achieved. This requirement has already been included in the EIAAA.

Further parameters are taken into account for alternate airport selection, such as the current flight route, direction, and altitude, as well as the surrounding airspace structure. The advantage of alternate airports located along the planned route is that the crew is already familiar with the route. Even if the flight is supposed to pass over this area at cruising altitude, the flight management system already stores waypoints, and the initial briefing package already includes special elements in the area and other important factors. Additionally, air traffic control is aware of the aircraft and ATC and the crew are already in communication. The current flight direction and altitude are taken into account, as well as the general flight route, since the crew's decision-making process in the cockpit takes time. However, during this time, the aircraft continues to fly at cruising speed around 450 kt (840 km/h). For this reason, the EIAAA prioritizes airports ahead of the aircraft's current position over those from which the aircraft is moving away. Of course, the system also analyzes alternatives behind the aircraft. People tend to favor solutions in the direction of movement, even though the best choice may lie behind them. This is comparable to the cabin crew's instruction to passengers that the nearest emergency exit may be behind them, contrary to their view. Obviously, technical systems are not subject to this kind of behavior. Nevertheless, we found that the crews tend to better accept an alternate airport "ahead." Pilots particularly favored a corridor of approximately 30 degrees to the left and right of the current flight direction matching their mental model. Additionally, the surrounding airspace is included in the assessment. Alternate airports that require complicated airspace navigation or avoidance of restricted airspaces during approach receive lower ratings than those that can be approached without significant additional cockpit task load. It must be kept in mind at this point that the trigger for the diversion directly influences further ATC handling. A "Mayday-case" is handled differently than a "Pan-Pan-case" or a diversion that is not an immediate emergency.

In the future, the decision-making process will also consider the political situation. It is envisioned that the system will be granted access to passenger and cargo lists. Based on this information, landings in countries where further handling or onward flights would be difficult due to political conflicts will be excluded. However, the availability of relevant data is currently being reviewed.

V. User Interface

Pilots interact with the EIAAA using the touch-based user interface displayed on the EFB. The interface (Fig. 2) is divided into two main areas. On the left side is the detail area; the information is presented to the crew. The right panel shows a map with the current flight route and the airports.

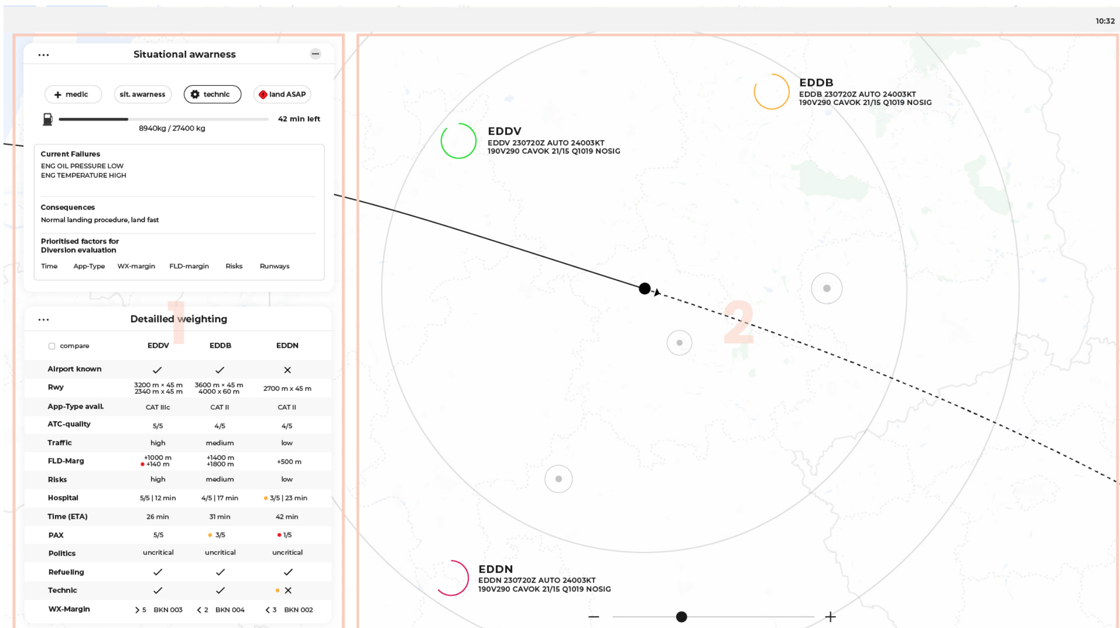

Fig. 2 User Interface of EIAAA displayed on the electronic flight bag in the cockpit

In the current design, the map area on the right side of the user interface is prominent. The interface design has been tested and evaluated with 18 airline pilots in several workshops. These evaluations did not reveal a significant clear opinion on the ratio of map area to area for pure data display. One group of pilots primarily focused on the EIAAA app when evaluating an alternate airport. This group rated the map as important. The other group primarily used the EIAAA app to process information but also used other cockpit displays, such as the navigation display with the map, to obtain information. This group considered an additional map display in EIAAA to be of secondary importance. A final design decision is expected in the next iteration of the system.

The map shows the aircraft's current position, the path already flown, and the planned route. Airports that are not currently rated high as alternate airports are displayed as gray icons. The three highest-rated airports in the current mode are color-coded. Green represents the highest rating, yellow represents the second-highest, and pink represents the third-highest. This color coding allows for a quick, high-level assessment. In addition to the color coding, a ring appears around the airport symbol (Fig. 3).

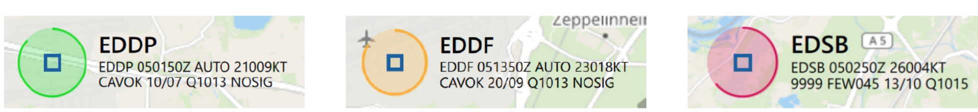

Fig. 3 The system selected three alternate airports, including the rating ring.

However, the difference in color alone does not indicate how far apart the three airports are in the ranking, Therefore, the ring fills up as the airport's rating improves. This visually shows how big the difference in ratings between the top three airports is. The concept does not provide any threshold values that could lead to multiple airports being rated as "very useful." This would again require pilots to conduct their own comprehensive analysis, which the system is designed to avoid. The EIAAA uses quantitative ratings for evaluation, so even if the second-ranked airport is only one rating point lower, it is still considered the second-best airport. Nevertheless, the rings allow for a quick comparison of the variance between airports. The current Meteorological Aerodrome Report (METAR) for the respective airport is displayed alongside the airport symbol, giving pilots a quick overview of the current weather conditions.

The upper right area is used for the app's primary controls. The previously mentioned modes can easily be selected here. Additionally, it displays the current fuel quantity on board the aircraft and the theoretical remaining flight time. These two values were always the first pieces of information requested by pilots, so they are permanently displayed, even though this information is already displayed in other places in the cockpit. Below, there the EIAAA self-explanation area is placed. The system provides information about current facts that could lead to a diversion. This is followed directly by the consequences that result from the facts. In the event of technical problems, information will be read directly from the aircraft in the future and displayed accordingly. In the event of medical incidents, the facts and possible consequences are presented here to support the pilots' decision-making process. Pilots experienced this as particularly helpful for communicating with medical personnel on the ground. As previously mentioned, the EIAAA uses a variety of weighted parameters depending on the situation to evaluate possible alternate airports. Factors given high priority in the current mode are displayed separately to the pilots. This allows the pilots to quickly determine if the system is selecting possible alternate airports consistent with their understanding of the situation. If there are discrepancies between the system's selection and the desired crew prioritization, they have the option of changing the factors' priority. The next area is a table, displaying the three highest-rated airports (Fig. 4).

Detailled weighting

☑ compare	EDDV	EDDB	EDDN
Airport known	3200 m × 45	3600 m × 45	2700 m x 45
App-Type	CAT 3	CAT 2	CAT 2
ATC-Env.	5/5	4/5	4/5
FLD-Marg	600 m	1000 m	● 100 m
Hospital	5/5	4/5	● 3/5
Time	26 min	31 min	42 min
PAX	5/5	● 3/5	5/5
Technic	✓	✓	● ✗
WX-Margin	EDDV	EDDB	EDDN
RWY number	1	1	1
Traffic	EDDV	EDDB	EDDN
Risks	EDDV	EDDB	EDDN
Ops	EDDV	EDDB	EDDN
Politics	5/5	5/5	5/5
Refueling	✓	✓	✓

Fig. 4 Details of the three highest-rated airports.

The table is sorted according to the weighting of the parameters. The strongest influencing parameters on the airport selection are at the top, presented in descending order. The individual pieces of information have different levels of detail. They range from simple yes/no information (e.g., whether the airport is known or if refueling or maintenance is available) to a 5-point rating scale (e.g., ATC quality, passenger handling, and medical service) to absolute values (e.g., runway details, weather forecasts, and available approach types). The information's level of detail can be temporarily increased by touching it. Pilots can switch the table to compare mode. In the compare mode, parameters that are the same for all three airports are depicted in light grayed and moved to a separate area at the end of the table. The other parameters remain fully visible and are sorted by priority. By streamlining the information, this compare mode ensures that pilots can focus on distinguishing factors between options.

In line with this approach, the app always presents the top three alternate airports. While the first two choices remain fixed to reflect the best options, pilots have the flexibility to substitute the third. This pilot's choice is designed for comparative purposes or to gain insight into why an airport is not the optimal choice in the context of prevailing circumstances. Pilots can mark their choices on the map. Once an airport is selected, it automatically becomes the pilot's choice and is marked with a color. The details can then be compared with the system first and second choices.

Regardless of the mode selected by the crew in the system, only airports allowing for a safe approach and landing within the limits of the aircraft manufacturer, regulatory authorities, and airline will be suggested. If, at any point during the flight, the crew must fly to the lower limits due to a lack of alternatives, the EIAAA will inform them separately. If no available airport is within the limits, the system will suggest airports with the lowest risk and inform the crew that the limits have been exceeded. In this case, the crew has the option to determine which limit they want to exceed intentionally.

VI. Establishing trust in the system

The aviation community highly values a support system that facilitates the intelligent and rapid selection of alternate airports. While the number of daily diversions underlines this need, individual pilots rarely encounter this problem during their careers. This immediately poses the research question on how a system should be designed to build trust so that the crew can use it optimally in an emergency without wasting time gathering information manually and making delayed decisions. In general, rare but critical events to flight safety are practiced in regular training sessions. It is unlikely that EIAAA will become part of regular simulator training. Nevertheless, pilots need regular positive experiences with the system to build trust in it. Ideally, EIAAA will reflect the mental models of pilots during flight so that they will trust the system's recommendations, leading them to use it as intended in an emergency. EIAAA actively supports this process through several elements. During normal flights, pilots can use EIAAA on the EFB. In Mode 1, Situational Awareness, it shows the three best alternate airports at any given time, assuming a reason for diversion could occur immediately at any time. This allows crews to comfortably use the system while having enough mental resources to compare its suggestions with their personal experience. Another way to compare the system with one's own experience during a normal flight is the Pilot's Choice Airport option. This option also explains how the system works. When a deviation from one's preferred selection occurs, it helps the person understand the factors that led to the difference. Then, they can question both their own choice and the system's selection. Again, this can be done during normal flight without the need of any technical failure or medical events.

Additionally, the pilot can choose to have the system explain why EIAAA prefers other airports. This feature is comparable to the way modern car navigation systems work. These systems now explain why a route was changed and provide information on how the change affects travel time, route length, and fuel consumption. Cockpit crews can also obtain similar information from EIAAA. The ability to simulate technical failures on the aircraft directly in the EFB app is currently being tested. In simulation mode, pilots can freely change flight parameters and select various malfunctions. The EIAAA then adjusts its recommendations according to the set limitations. This feature is intended to increase acceptance of alternate airport recommendations. In addition to system accuracy, the quality of the data used for analysis is also crucial. EIAAA can best demonstrate its strengths when it receives the most up-to-date and reliable data for analysis. With constantly improving data connections in the air and increasing automation of data collection on the ground , shorter update cycles in aviation can be envisioned. Meanwhile, it is already possible to supplement aviation information with data from other sources. EIAAA once again supports pilots' confidence through transparent communication in this area. Pilots can verify the source and timeliness of any information processed in the system. The system proactively reports when information does not come from aviation-certified sources.

VII. Conclusion

Several workshops with professional pilots at the German Aerospace Center (DLR) have highlighted the need for an intelligent and explanatory alternate airport assistant. According to independent sources, the number of diversions remains consistently high. Additionally, decision-making is complicated by the growing number of parameters that must be considered in modern aviation. These include optimal passenger handling amid an increasing passenger volume, airspace closures due to political developments at very short notice, and pressure on airlines to make efficient decisions. In the future, it is conceivable that climate-optimized factors could be incorporated into the system as well.

Various concepts for airport evaluation and user interface design have already been developed in ongoing research projects at DLR and are continuously evaluated by aviation experts. The results presented in this paper were evaluated as prototypes with commercial pilots. The DLR HAWKEYE project, initiated in 2025, will elevate the overall system to TRL-7 and initiate its market introduction.

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